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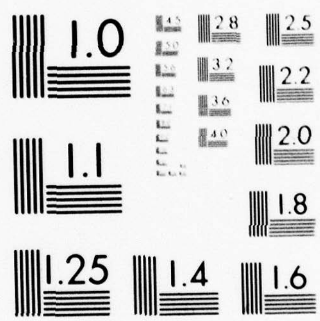

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REPORT NO. CG-D-05-79

DEVELOPMENT OF A STREAMING-FIBER OIL SPILL CONTROL SYSTEM STAGE II - MODIFICATIONS TO LARGE-SCALE MODEL

R. L. Beach
D. W. Durfee

Seaward International, Inc.
6269 Leesburg Pike
Falls Church, Virginia 22044

August 1978

FINAL REPORT

PREPARED FOR

U.S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
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6269 Leesburg Pike, Suite 204
Falls Church, Virginia 22044

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16. Abstract

The large-scale model of the Streaming-Fiber fast current oil skimmer was modified to improve performance in waves and viscous oils. Modification included a sorbent foam belt rotating beneath the fiber array to intercept and collect any oil escaping from the fibers, and separate flotation for the fiber array to improve wave conformance by decoupling the array motions from the skimmer vessel. Testing indicated benefits from both of these modifications. The program involved small-scale foam capacity tests and small-scale model tests, as well as testing of the large-scale model at OHMSETT. A preliminary prototype design, utilizing the most promising developments to date, is included in the report.

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FOREWORD

This report presents the results of a development program to improve performance of the streaming-fiber large-scale oil skimmer model. Seaward International, Inc., performed this work under Contract DOT-CG-40217-A, during the period January 1977 to August 1978.

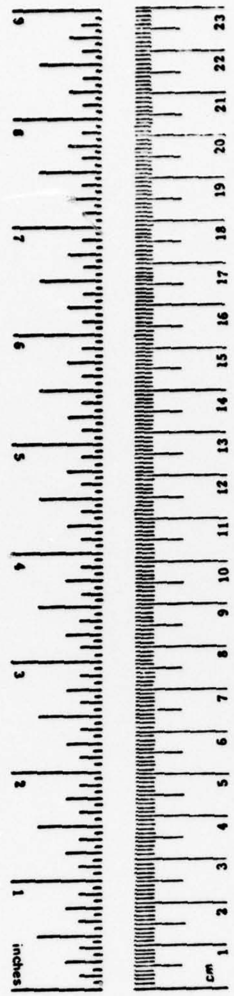
LCDR W. W. Becker and LT J. H. Getman of the U. S. Coast Guard served as Project Officers during this program. R. L. Beach served as Project Manager from Seaward International, Inc. Development work was performed by D. W. Durfee and R. L. Beach, with invaluable assistance from M. Krenitsky, E. Shildtknecht, J. D. Brown, P. F. Brown, F. J. MacDonald, and others.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

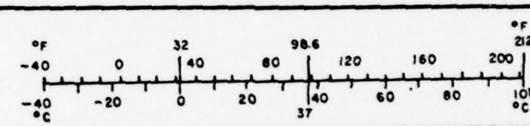
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS AND SYMBOLS

cp	Centipoise
D_{pore}	Nominal pore diameter of polyurethane foam
fps	Feet per second velocity
g_c	Gravitational constant conversion factor
ppi	Pores per inch (of foam)
T	Wave period
U	Superficial water velocity through the foam belt
We	Weber number
ΔP	Pressure drop
σ_{ow}	Interfacial tension (IFT)
ρ_{ω}	Density of water

1.0 SUMMARY

The large-scale model of the streaming fiber oil skimming device was modified with several new concepts to improve both performance in waves and in recovering viscous oils. These concepts included:

1. A sorbent belt (polyurethane foam) rotating beneath the fiber array, to intercept and filter out any oil that escapes through the fibers because of entrainment.

2. Fiber support modules that are floated independently of the hull to improve wave conformance.

3. The ability to introduce considerable slack in the fibers to provide additional wave conformance.

4. A floating oil pickup head, to recover oil squeezed from the foam belt and oil thickened by the fibers in their normal function.

In developing these concepts, small-scale testing was performed in the Coast Guard's circulating flume, located at Seaward's facility in Clearbrook, Virginia. These tests provided data on the foam belt oil retention capacity, and demonstrated the feasibility of using the belt concept in this configuration.

Tests on the modified large-scale model were later begun at the OHMSETT test facility, but were terminated because of mechanical failures in the belt drive mechanism. Preliminary indications were that the belt was beneficial to the oil recovery performance. Improved wave conformance of the fiber

array was demonstrated, but without the belt present no improvement in recovery performance was shown. The performance of the slack fibers could not be evaluated directly, but they did not appear to be benefiting the recovery performance.

As a result of these tests, recommendations were made to develop a positive, roller-chain drive system for the belt, eliminate the slackness in the fibers and belt (retain the floating fiber array concept, however), and dimensionally stabilize the structure. These and other recommendations are presented in the report in the form of a preliminary prototype design, utilizing the best features of the streaming fiber concept as developed so far.

2.0 INTRODUCTION

In response to the Coast Guard's need for a fast-current oil skimming system, Seaward International, Inc., undertook the present development program. In Stage I[1] of the program, the feasibility of using an array of streaming fibers to slow down and recover a fast-moving oil slick was demonstrated. Several areas for additional development were identified, and initial work in Stage II concentrated on these areas.

In its simplest form (taut fibers, no belts), the streaming-fiber concept worked well at speeds of up to 4 - 5 knots in calm water and with light oil. Two basic problems were apparent, however; oil slowed down faster than the underlying water, causing a head wave and entrainment within the fiber bundle; and, secondly, viscous oil was difficult to remove from the fibers.

Studies conducted initially during Stage II[2] showed that viscous oils could be recovered if the fibers were lowered below the surface so that the oil could flow to the area of the pickup device (rear). A conveyor belt traveling on top of the oil layer was also found to aid the flow of oil towards the rear. As such, the concept was a significant advancement over prior technology in recovering oil at high current speeds in calm water.

The design for a large-scale model was then developed. By incorporating this design into the modified hull of an available commercial skimmer, a large-scale model capable of actual cleanup operations was constructed. Testing of this model was performed at the EPA's OHMSETT test facility in Leonardo, New Jersey, during 1976. However, wave tests of the model showed that strong transverse (vertical) motions across the fibers caused severe oil-water mixing and heavy oil losses.

If application of the streaming-fiber concept were to approach Coast Guard objectives for a fast-current skimmer, especially in wave performance, such problems would have to be minimized. Although no assurances could be made, it appeared that certain new features, which were finally implemented on the large-scale model and reported herein, would offer the best chance of minimizing the performance problems. However, it was also recognized that increased mechanical complexity, with an attendant new set of problems, would result. The principal new features were to include:

1. Floating fiber supports to improve wave conformance and allow variable fiber submergence.
2. A flexible polyurethane foam belt rotating beneath the fibers to capture oil that escaped through the fiber array.
3. Adjustable fiber and belt sag to help improve wave conformance.
4. A floating oil pickup head to remove the oil squeezed out of the belt, rather than the existing stationary weir design.

This report presents the results of the development program carried out to evaluate these new features. Both the small-scale testing in the laboratory and flume, and the large-scale model tests at OHMSETT during the summer of 1977 are discussed.

3.0 SYSTEM DEVELOPMENT

3.1 Design Concept

The design goals that were to be met through modification of the large-scale model include the following:

1. Operational Environment

   Up to 6 knots current with optimal recovery in the 2 to 4-knot range and 2-feet confused sea with 20-knot winds.

2. Minimum Oil Thickness

   0.04"

3. Oil Type

   Complete range of oils including distillate fuel oil, residual fuel oil, and crude oil, with optimum recovery to be in the range of 10 cs to 500 cs.

4. Recovery Function

   A. Throughput Efficiency $\geq$ 95%
   B. Recovery Efficiency $\geq$ 75%
   C. Recovery Rate up to 43 gpm per foot of fiber array width.

In principle, the modified large-scale model would function like the original model; streaming fibers would slow down the oil and water, and the oil would be moved to a common point to be picked up by a pump. The major differences are that the fibers and the fiber supports in the modified design would be free-floating to conform to the wave profile, and oil transport to the common collection point would be assisted by an oleophilic, porous belt sweeping beneath the fibers, rather than above.

The principal features of the revised concept are shown schematically in Figure 1. (Figure 2 shows the concept before the modifications were made, for comparison purposes.) The fibers are supported on support bars similar to the original model, but the support bars and plates are attached to floats instead of a rigid framework. The rear support section pivots on long arms attached to front part of the hull, with the front support section attached to the rear section by similar pivoting (turnbuckle) arms. By varying the length of the turnbuckle arms, the slack in the

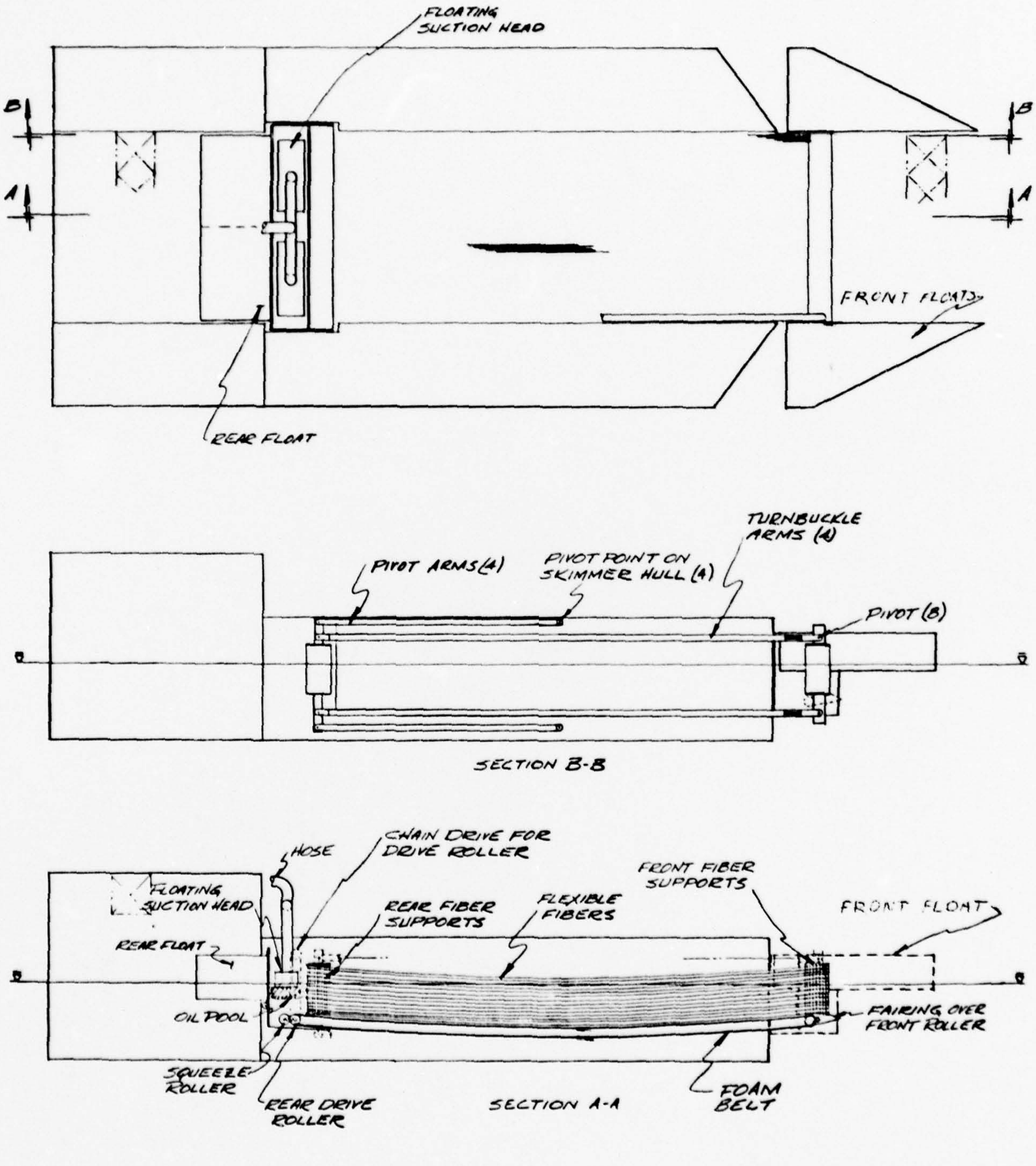


FIGURE 1. SCHEMATIC CONCEPT--MODIFICATION TO LARGE-SCALE MODEL

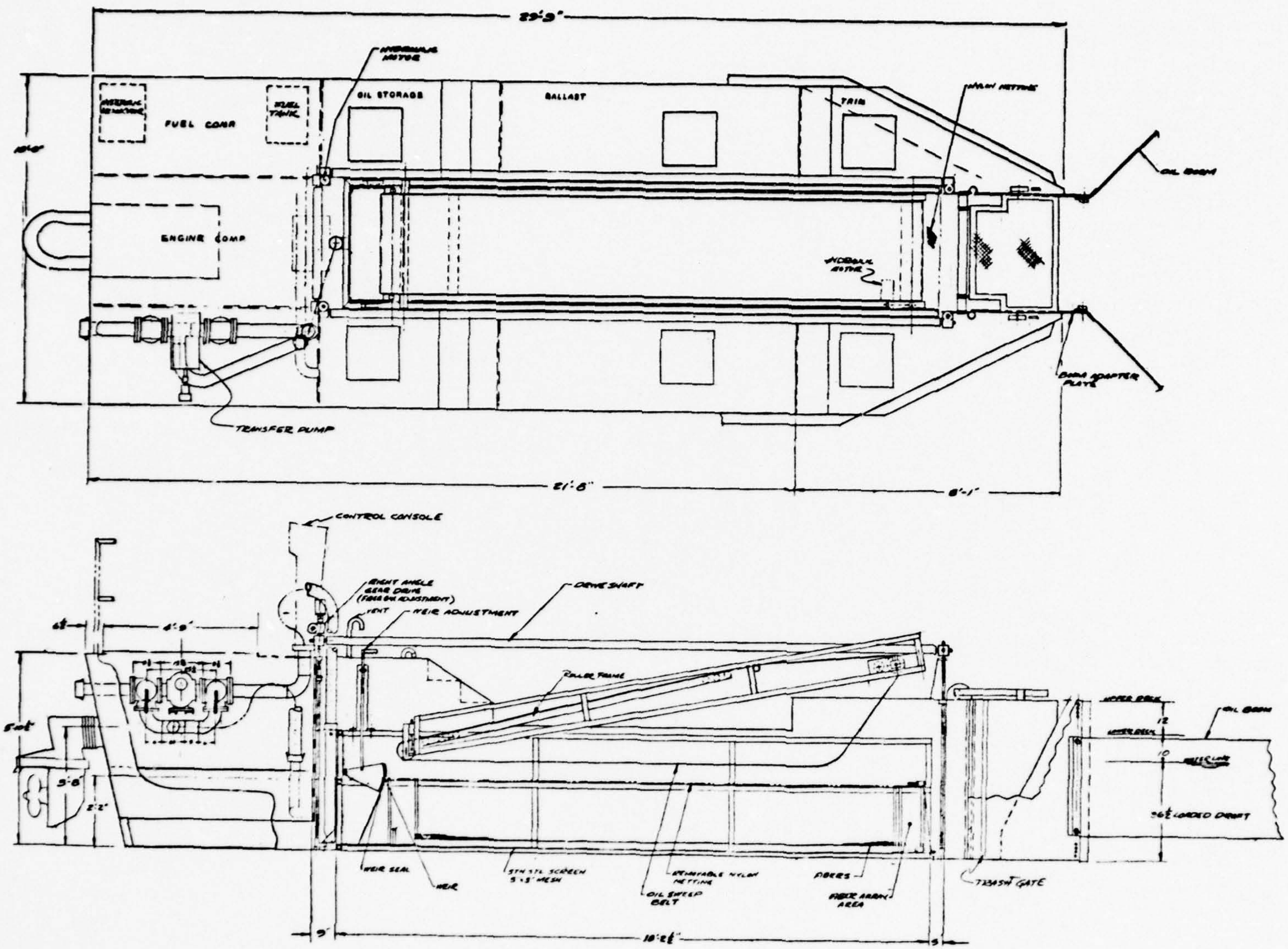


FIGURE 2. GENERAL ARRANGEMENT OF LARGE-SCALE MODEL BEFORE MODIFICATION

fibers can be adjusted to conform to the type of wave conditions encountered.

Beneath the fibers is an endless, rotating, porous (foam) belt with rollers attached to the front and rear supports. At the rear fiber support, a squeeze roller compresses the belt, and the expressed oil floats to the top of the sump chamber where the oil is pumped off through a floating suction head.

3.2 Belt System Design Considerations

The purpose of the foam belt is to intercept and absorb any oil that may escape through the bottom of the fiber array. From initial work on the fiber system, the velocity profile of the water flowing out the bottom was predicted to be nearly linear, being maximum at the front of the array and near zero at some downstream point, which depended on the skimmer forward velocity. However, maximum vertical water velocities through the belt could be an order of magnitude lower than the forward velocity, depending on the ratio of the frontal area of the fibers (below the waterline) to the bottom area. Oil losses were observed to be heavier somewhat up-stream of the zero-velocity point in the fiber array, at the point where the oil headwave formed, but still in the region where the water outflow velocity was low. Therefore, with the belt present, the oil would tend to be absorbed where the flushing action of the water was minimal. The oil would then be squeezed out of the belt and recovered in a quiescent region behind the fiber array. It was recognized that flow resistance in the belt (two layers) could possibly disturb the predicted outflow velocity profile, tending to even out the flow along the length of the fibers and belt. Blockage of flow into the device could also result, causing bypassing of the oil around the sides of the skimming device.

The fundamental questions that required answers were: 1) how much oil can be retained in a foam belt in the presence of a water flow, and 2) what is the pressure drop through the belt? To provide these answers, a small experimental program was untertaken.

3.3 Foam Tests

The object of these tests was to determine how much oil the foam would hold under the velocity conditions expected to exist in the large-scale model. Early attempts to generate this data tried to simulate the velocity-time profile that a section of the foam belt would see during its transit from the front to the rear of the skimmer. However, control of the oil input rate profile was difficult, causing erratic results. Also, it was not known whether or not the droplet sizes represented conditions that might be encountered in the skimmer. For these reasons, this approach was discontinued.

A simpler test was devised in which a foam sample, saturated with pure oil, was subjected to a flow of water at a known velocity. After exposing the sample to the flow for a duration exceeding the expected contact time in the large-scale model, the amount of oil remaining in the sample was measured.

A sketch of the apparatus is shown in Figure 3 . The flow passage was constructed of three-inch piping and Kamlock fittings. Water was taken from the flume and pumped through the apparatus using a calibrated positive displacement pump. To ensure that the piping ran liquid-filled, the vent valve was opened and the air was forced out. A one-inch thick, cylindrically-shaped foam sample was saturated with oil and placed in the sample section (a Kamlok fitting) before it was installed on the pipe. To do this, a cover was placed under the sample section and oil was poured into the foam until there was a thin layer of free-standing oil on top. The sample section was quickly installed on the pipe while the water was flowing, and held in place until a constant amount of water had passed through (approximately eight seconds flow at the lowest velocity). The sample was then carefully removed and quickly placed in a beaker for weighing.

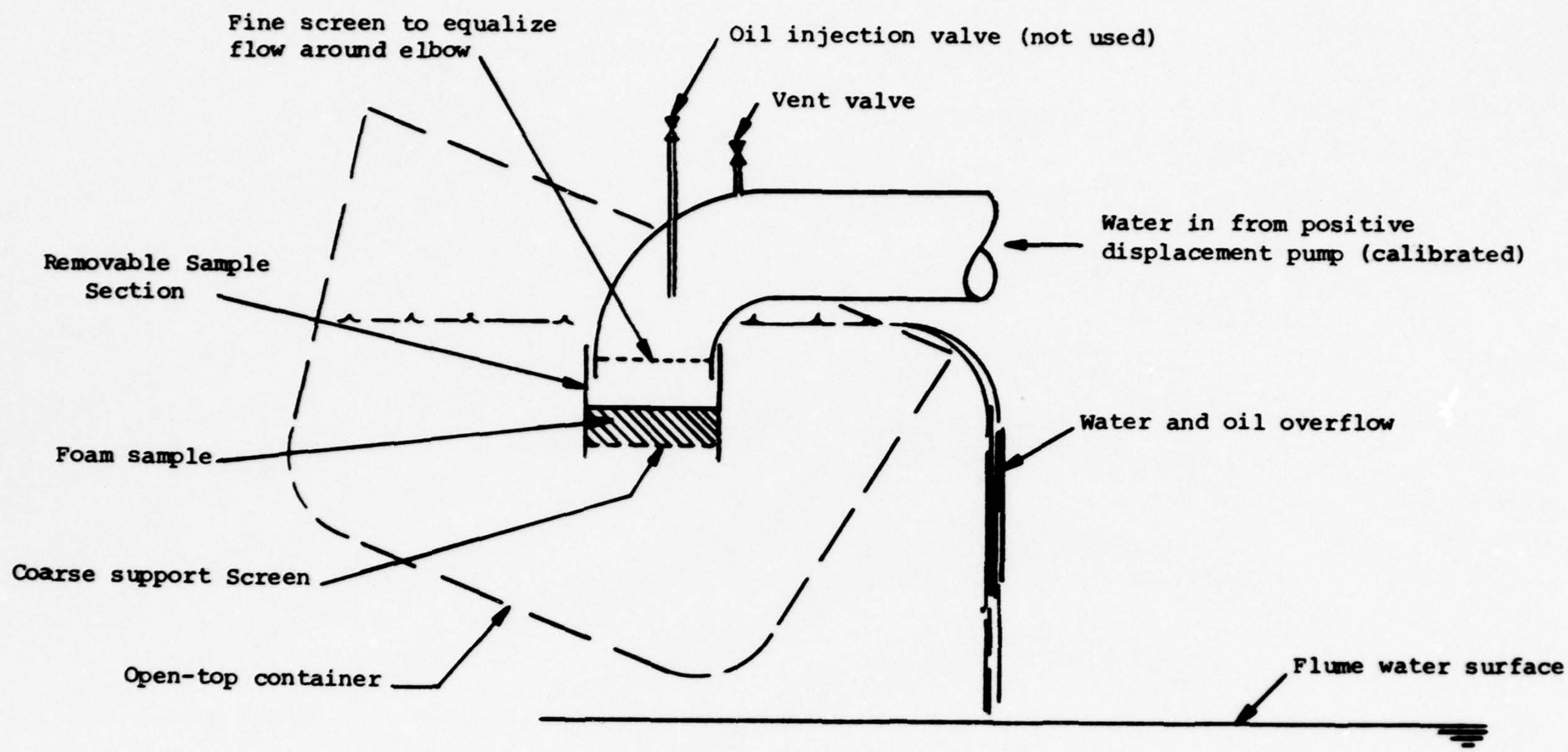


FIGURE 3. FOAM RETENTION CAPACITY TEST APPARATUS

After recording the total weight (foam, oil, water) the amount of oil present was determined by subtracting the weight of water squeezed from the foam (measured volumetrically) and the foam weight itself (measured before the test) from the total weight. This quantity (as a volume) was then divided by the foam sample volume to calculate a loading fraction.

Three different foam pore sizes were tested--10 ppi, 20 ppi, and 30 ppi. Oils tested were No. 2 fuel oil (3.3 cp, 20.8 dyne/cm IFT, and 0.850 s.g.), Coray 65 (623 cp, 24.2 dyne/cm IFT, and 0.908 s.g.), and Security 53 (300 cp, 28.05 dyne/cm IFT, and 0.875 s.g.). The maximum velocity tested was one foot per second, which is close to the maximum velocity anticipated in the large-scale model. The results for Coray 65 and No. 2 fuel oil are shown in Figure 4. The accuracy of the data is estimated as ± 0.02 on fraction of oil retained.

An attempt was made to correlate the data with certain of the experimental variables. The basic absorption mechanism, as discussed by Moses and Blackstone[3], involves preferential wetting of the foam by the oil, with accumulation of the oil droplets at the foam nodes, stabilized by surface tension effects among the oil, water, and foam surfaces. Although an extensive investigation of the variables was not undertaken, the importance of the interfacial tension in the absorption mechanism indicated a possible correlation of the fraction of oil retained with a Weber number, which was defined as:

$$We = \frac{\rho_w \; U^2 \; D_{pore}}{\sigma_{ow} \; g_c} \qquad (1)$$

Where:
- We = Weber number
- ρ_w = water density, lb_m/ft^3
- U = superficial water velocity, based on foam frontal area, ft/sec
- D_{pore} = nominal pore diameter (1/pores per unit length), ft
- σ_{ow} = interfacial tension, lb_f/ft
- g_c = $32.17 \; \frac{lb_m \cdot ft}{lb_f \cdot sec^2}$

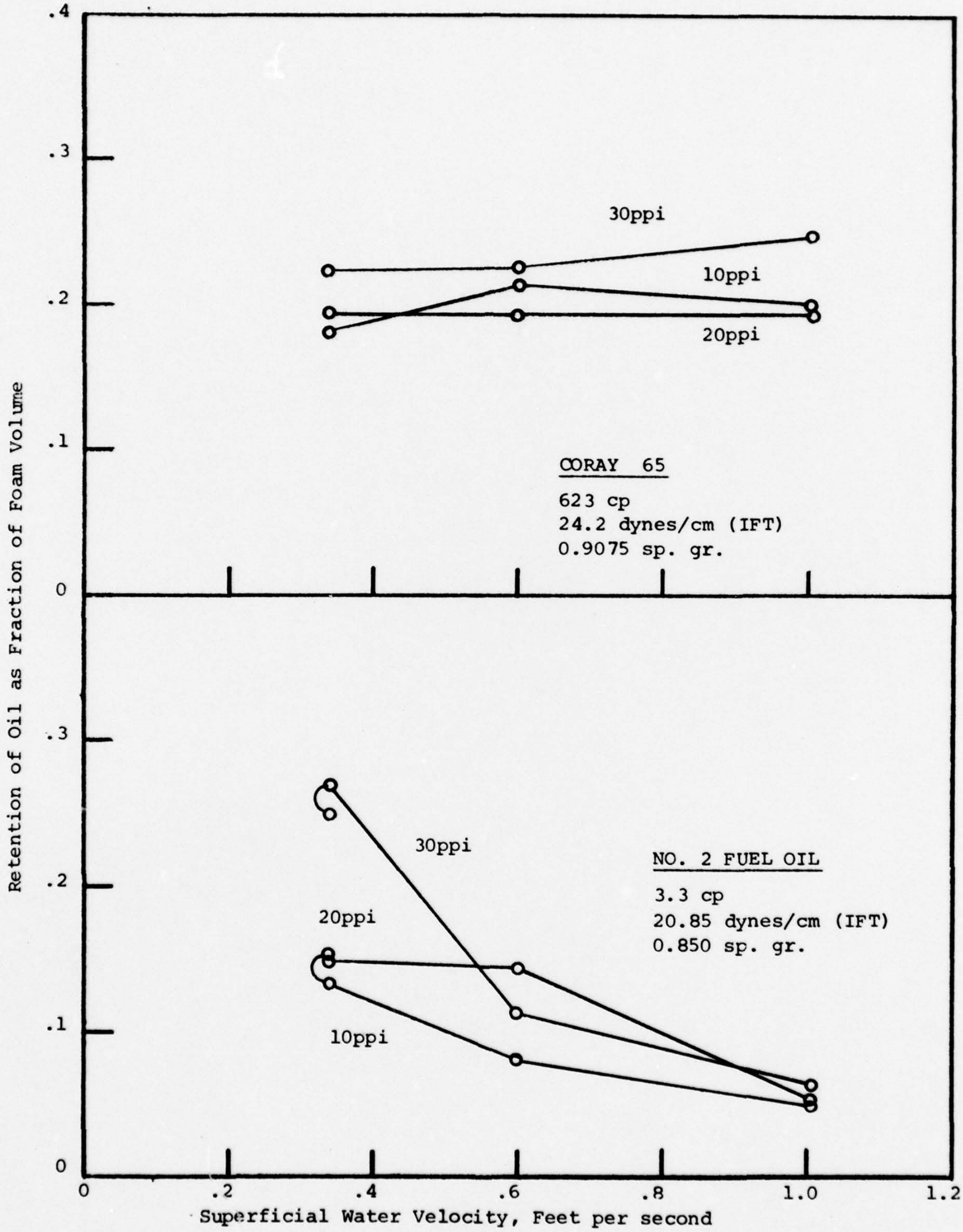


FIGURE 4. OIL RETENTION IN RETICULATED POLYURETHANE FOAM IN PRESENCE OF WATER FLOW

The Weber number, as defined above, represents a ratio of the inertial forces imposed by the water flowing through the foam to the interfacial tension forces stabilizing the oil in the foam. With the low-viscosity No. 2 fuel oil, a reasonable correlation was obtained, as indicated by the line in Figure 5, even though interfacial tension was not a variable. However, with the viscous oils no similar correlation was obtained, as indicated in Figure 6. In fact, a nearly constant retention of approximately 21 percent was observed. A correlation with Reynolds number was not obtained either (using oil viscosity, water velocity, and pore size as parameters), suggesting that the high oil viscosities retard the sweeping of the oil from the foam, preventing attainment of equilibrium within the relatively short exposure times utilized in these tests. Such a retarding effect would be an advantage in a belt system, where the time of exposure to the higher water velocities would be relatively short.

With the belt configuration used in the skimmer, the problem is not only in retaining absorbed oil in the matrix, but in absorbing the oil in the first place. When relatively large drop sizes (compared to the pore size) encounter the foam, the tortuous path through the matrix ensures droplet contact and the potential for absorption. However, relatively small drops may be less inclined to absorb, partly because of the water motion "steering" the droplets through the pores, and partly because of the reduced tendancy of the more stable smaller droplets to rupture and adhere to the surface upon impact. As the skimmer speed and the amount of energy to be dissipated increases (proportional to the square of the velocity), the oil droplets produced by shearing and entrainment will tend to decrease in size, thus reducing the effectiveness of the belt system.

The pressure drop of the water through the foam was also measured, using the same apparatus described above, with the

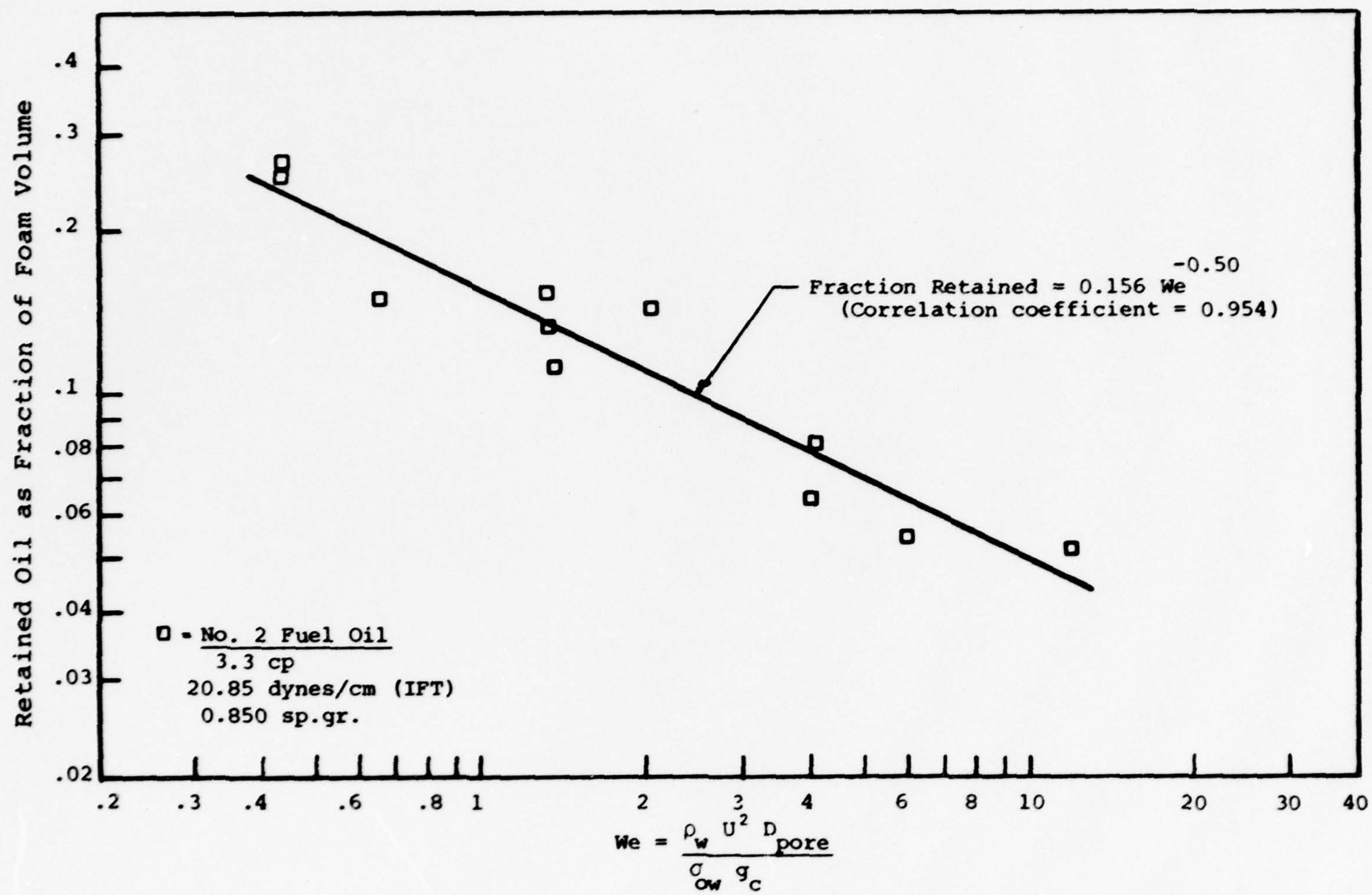
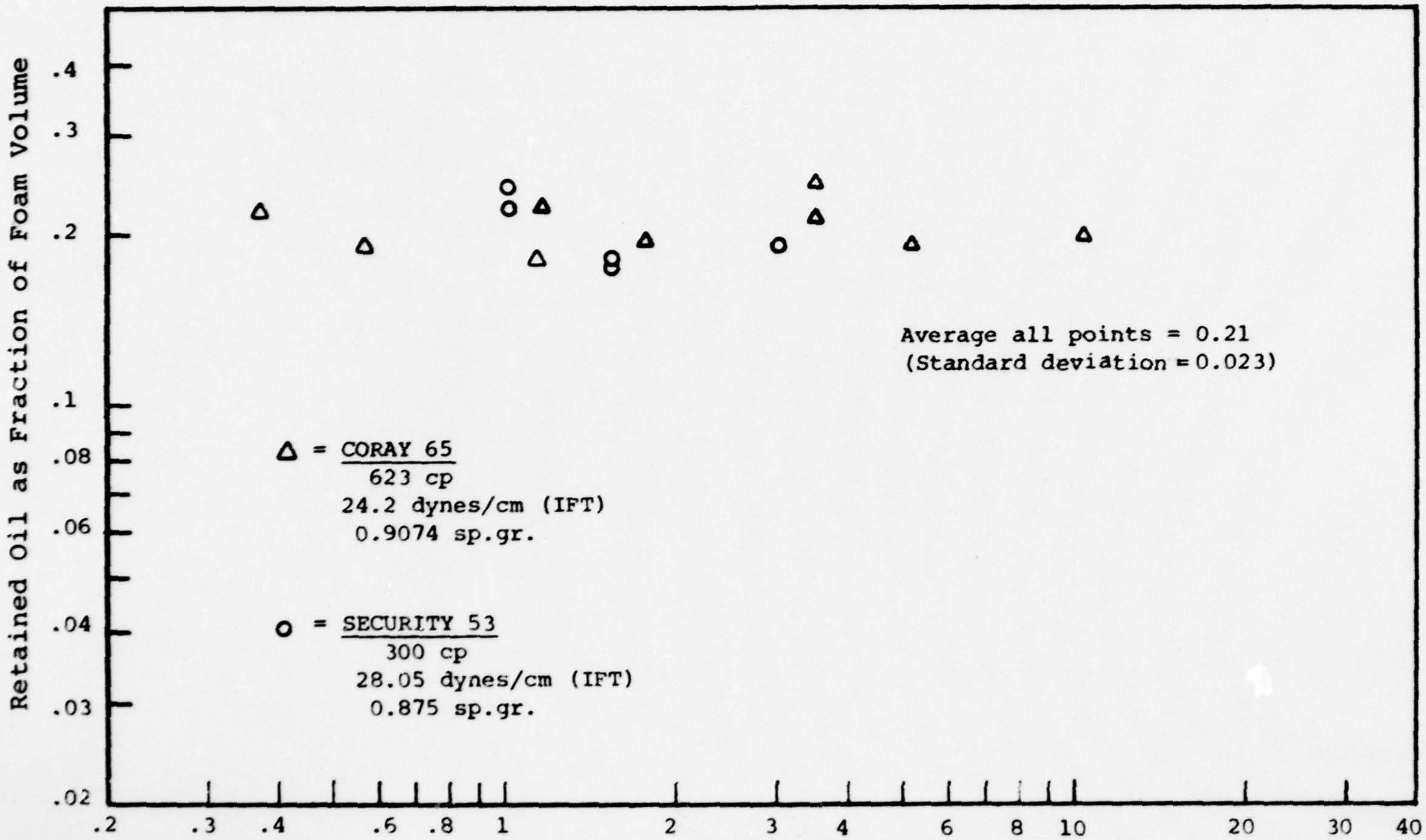


FIGURE 5. RETAINED OIL FRACTION IN POLYURETHANE FOAM AS FUNCTION OF WEBER NUMBER FOR LOW VISCOSITY OIL



$$We = \frac{\rho_w U^2 D_{pore}}{\sigma_{ow} g_c}$$

FIGURE 6. RETAINED OIL FRACTION IN POLYURETHANE FOAM AS FUNCTION OF WEBER NUMBER FOR VISCOUS OILS

addition of a manometer to measure the head loss. These data are shown in Figure 7. Although 30-ppi foam showed the potential for retaining nearly twice as much low-viscosity oil as the 10-ppi foam, the pressure drop was three times as great. Since low-viscosity oil did not appear to produce as much entrainment as high-viscosity oil in previous testing, and the retention of viscous oil appeared to be relatively independent of pore size, the 10-ppi foam was selected for use in the large-scale model.

3.4 Flume Tests

To test the new concepts on a small scale, the small-scale model used in previous tests[1,2] was modified with the addition of a foam belt and squeeze roller assembly, and a floating oil pickup head. The fibers could be adjusted to provide several inches of slack to test wave conformance, but floating end supports for the fibers were not provided.

The Coast Guard's circulating flume, located at Seaward's Clearbrook, Virginia, facility, was modified to include a flapper-type wave maker which was capable of generating up to nine-inch waves of one-second period in certain regions of the flume. The model depth in the water could be adjusted. Figure 8 shows a schematic drawing of the model in the flume.

To estimate the throughput efficiency, measurements of oil and water volumes in the holding tanks were made before and after each run, and the net difference was assumed to be oil loss (the difference in oil holdup in the model before and after the run was also factored into the calculations). The accuracy of the procedure was maximized by making long runs of 6 to 25 minutes duration, depending on the oil feed rate. Errors were estimated to be on the order of ± 3 percent on throughput efficiency. Throughput efficiency was defined as:

$$\frac{\text{volume oil recovered + increase in oil holdup in the model}}{\text{volume oil fed}} \times 100\% = \text{Throughput efficiency \%} \qquad (2)$$

The results of the flume tests are summarized in Table 1. In general, the test results indicated that the belt system and slack fiber concept were beneficial to the model performance, and should be confirmed by wave testing in the large-scale model at OHMSETT.

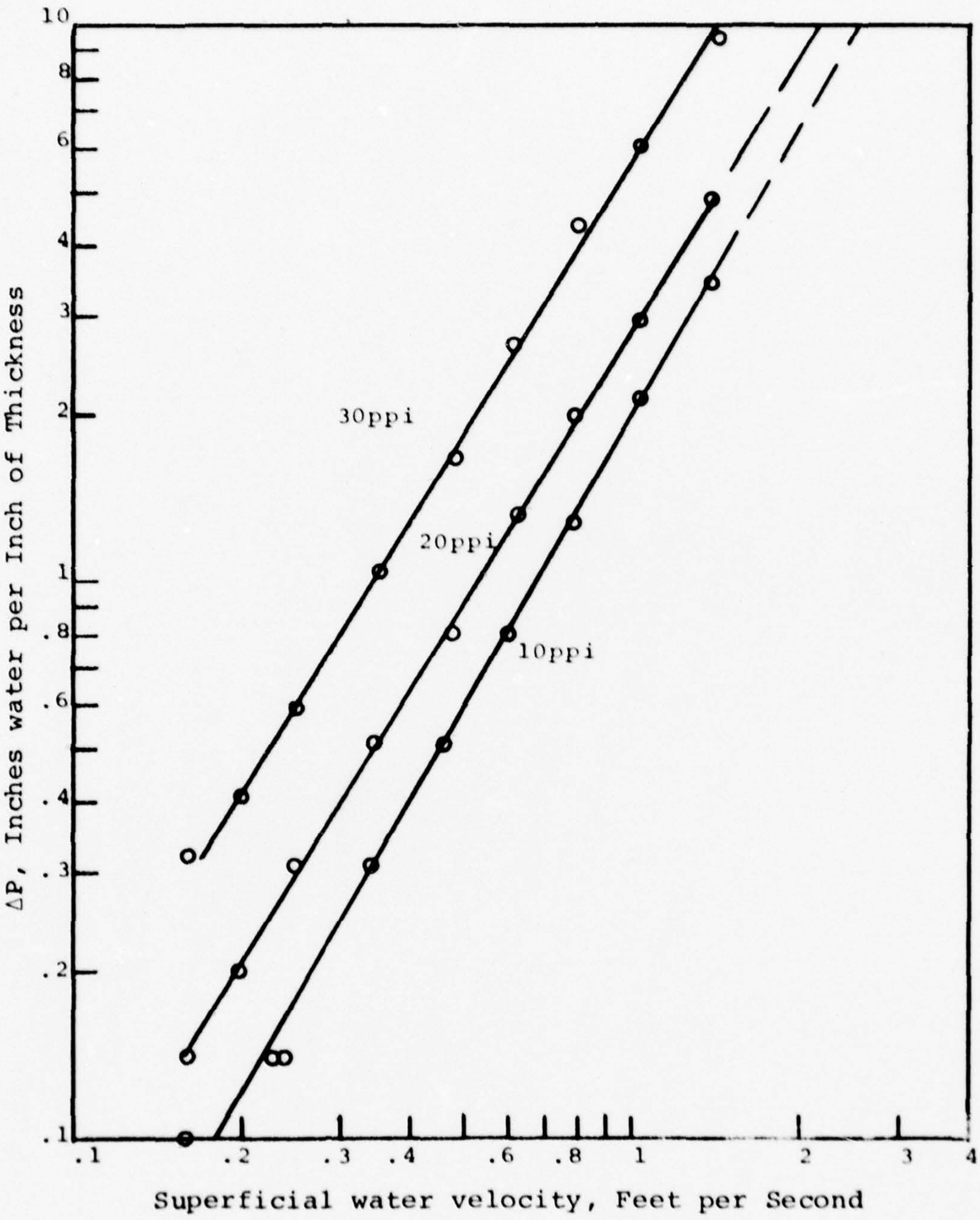


FIGURE 7. PRESSURE DROP OF WATER THROUGH POLYURETHANE FOAM

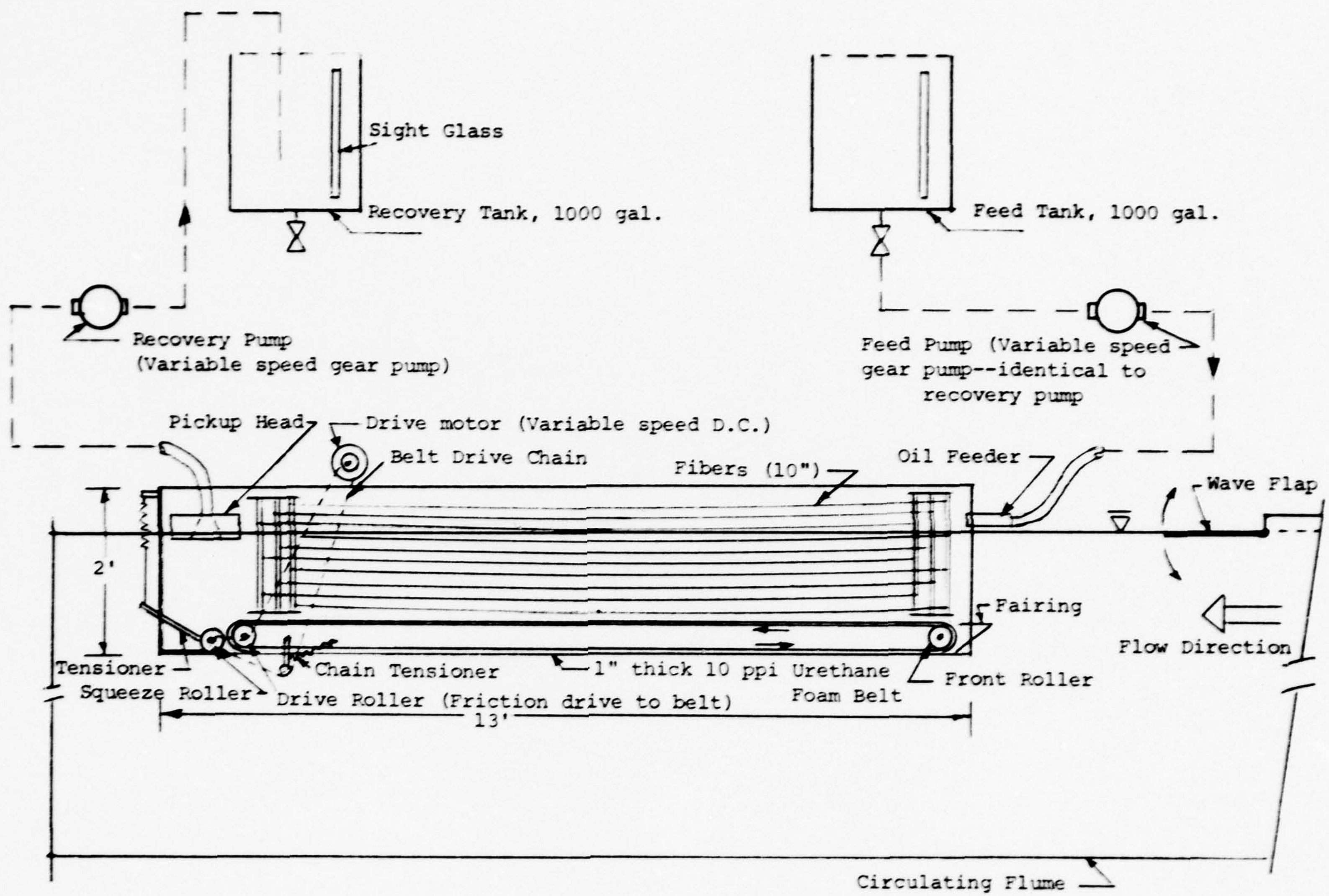


FIGURE 8. SCHEMATIC OF SMALL-SCALE MODEL IN THE CIRCULATING FLUME

TABLE 1. FAST CURRENT FLUME TESTS - SUMMARY OF RESULTS

Test No.	Oil & Vis, cp	Flume Speed	Waves	Belt	Fiber Depth	Fiber Tension	Feed gpm	Throughput Efficiency %	Comments
1	Sec 53, 125 cp @ 66°F	2/3 (4-5 fps)	last half of run, T = 1.03 sec, 6-10"	4 fps	12 in.	slack 3"	8.2	77%	Possible losses around sides of belt - also recovery pump probably not picking up during whole run, causing overloading.
2	"	Full (7-8 fps)	No	4 fps	12 in.	slack 3"	8.0	80%	Same comments as in #1.
3	"	Full	No	5.2 fps	12 in.	slack 3"	9.9	92%	Belt seals installed, recovery pump may have lost suction.
4	"	Full	No	5.2 fps	12 in.	slack 3"	4.9	93%	May still have had recovery pump problems - lower oil rate.
5	"	2/3	Yes (like #1) (4" inside model)	5.2 fps	12 in.	slack 3"	4.9	38%	Motor belt slipped, recovery pump didn't pick up - wasted run.
6	Sec 53, 114 cp @ 68°F SG 0.875	2/3	Yes (like #1)	Removed	12 in.	slack 3"	4.9	92%	Recovery pump had not picked up until run 1/2 over.
7	Sec 53, 120 cp @ 68°F	2/3	Yes (like #1)	Removed	12 in.	straight	4.9	87%	Pick-up uncertainties solved - See Run #6 - indicates advantage to slack fibers
8	Sec 53, 103 cp @ 72°F	Full	No	Removed	12 in.	straight	9.9	97%	Efficiency doubtful because of two previous runs of oil already in recovery tank.

TABLE 1. FAST CURRENT FLUME TESTS - SUMMARY OF RESULTS (CONTD.)

Test No.	Oil & Vis, cp	Flume Speed	Waves	Belt	Fiber Depth	Fiber Tension	Feed gpm	Throughput Efficiency %	Comments
9	Sec 53, 103 cp @ 72°F	Full	No	Removed	12 in.	straight	9.9	90%	Repeat of Run #8 - improved test procedure.
10	Esstic 65, 440 cp @ 71°F, SG = 0.90 - Fresh	Full	No	Removed	12 in.	straight	9.9	86%	Effect of vis. oil - Compare to Run #9.
11	" - Fresh	2/3	Yes (max stroke, T=1 sec)	Removed	6 in.	straight	13	75%	Less fiber submergence and higher oil rate - to increase test severity.
12	" - Fresh	2/3	Yes (max. stroke, T=1 sec)	5.2 fps	6 in.	straight	13	93%	Compare to run #11 - shows advantage of belt.
13	" - Used	<1/3 (2.3 fps)	No	5.2 fps	6 in.	straight	13	103%	Effect of higher belt loading - shows approx. errors in testing ±3%.
14	" - Used	2/3	Yes (max.)	5.2 fps	6 in.	slack	13	99%	Effect of belt + slack fibers - compare to Run #12.

3.5 OHMSETT Tests

Model Description: The large-scale model used in the 1976 OHMSETT tests was modified to incorporate the changes discussed above. A view of the model in the water is shown in Figure 9. Figure 10 shows the major features. Several features of the model are discussed in more detail below:

1. Fiber array: Figure 11 shows a side view of the fibers during assembly of the array. Also shown is the foam belt and two of the four pivoting turnbuckle arms connecting the rear (on the left in the figure) and the forward floating modules together. The arms permit independent heaving of the front and rear sections without appreciably changing the sag of the fiber and belt support cables. The slackness of the fibers and the belt could be adjusted simultaneously by turning all four turnbuckle arms an equal amount. The fiber array width was reduced to 36 inches so that it would fit between the bow sections. The same support bars and support plates were used as before. Fiber spacing, length, and other parameters were also kept the same.

2. Foam belt: The belt was constructed of 10-ppi Scott reticulated foam, one-inch thick and 35 inches wide. Figure 12 shows a top view of the belt installed in the skimmer. The connecting link can be seen next to the elastomer-coated squeeze roller. A close-up of a typical polyester tension-strap joint is shown in Figure 13. The foam is sandwiched between the one-inch wide tension strap and a strap of Velcro loop tape, which is used to drive the belt through contact with stubble tape riveted to the front and rear drive rollers. Crosswise polyester straps were also sewn onto the belt in sandwich fashion, at approximately six-foot intervals. To provide support for the

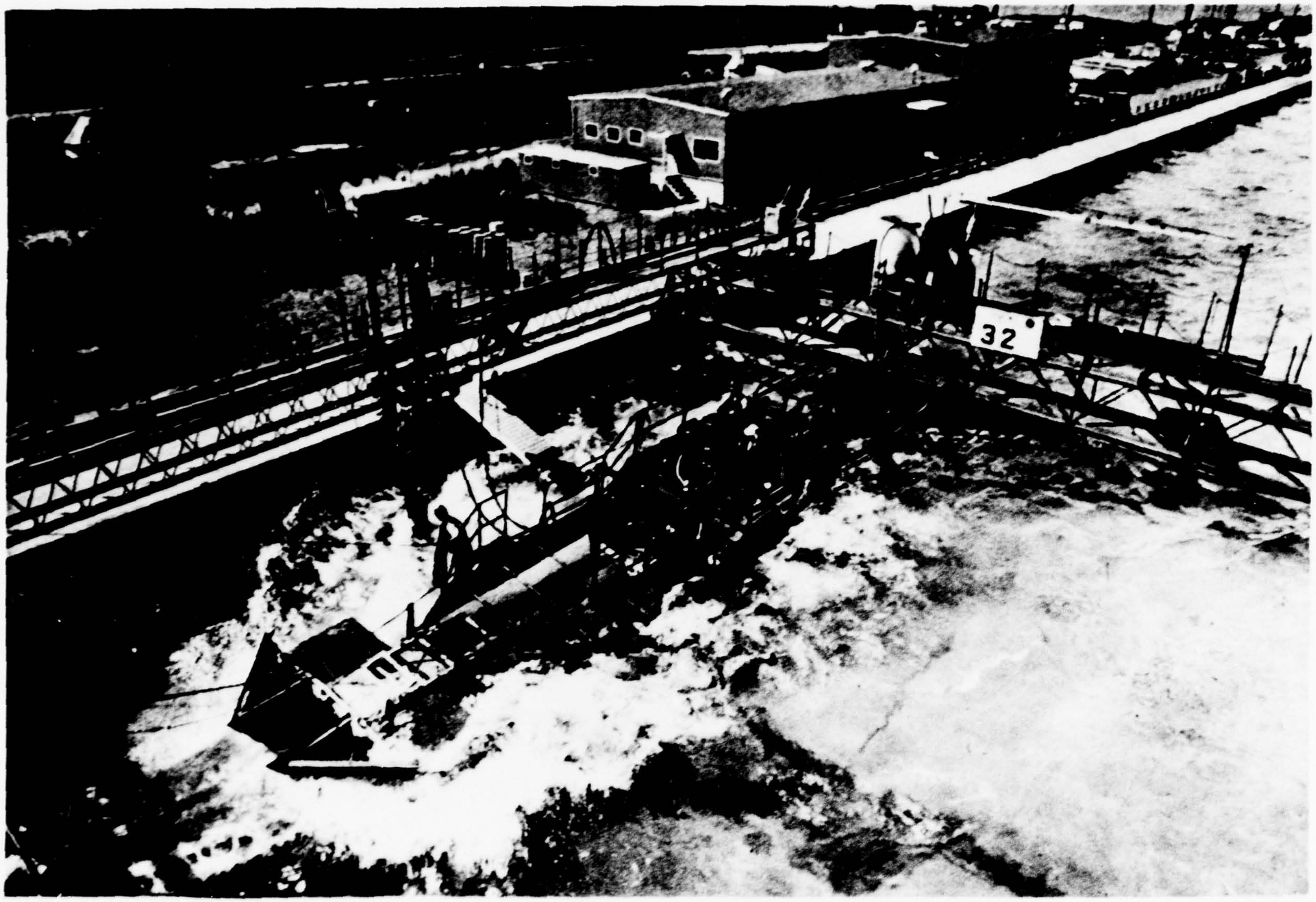


FIGURE 9. LARGE-SCALE MODEL DURING HIGH SPEED WAVE TEST

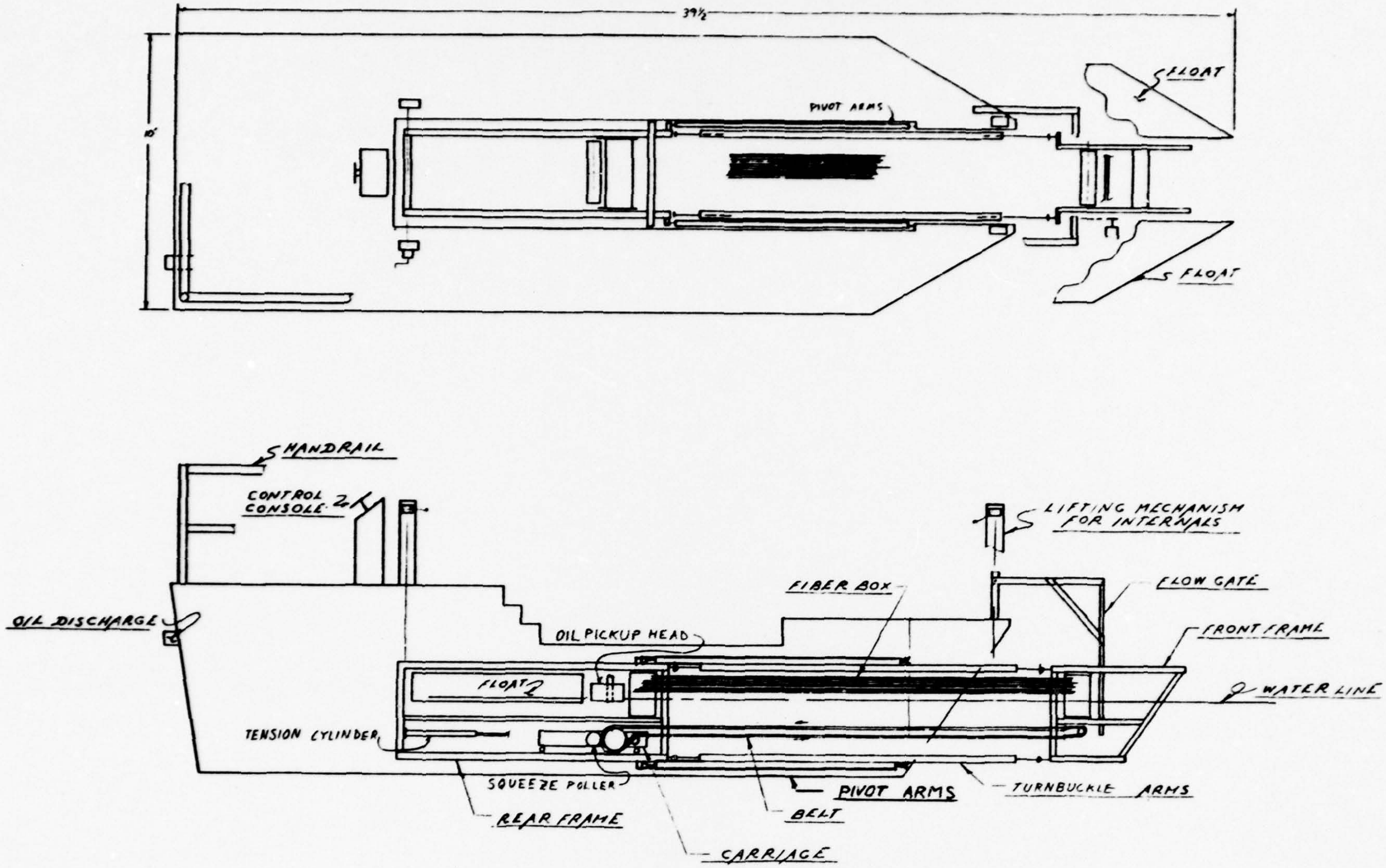


FIGURE 10. LARGE-SCALE MODEL FEATURES

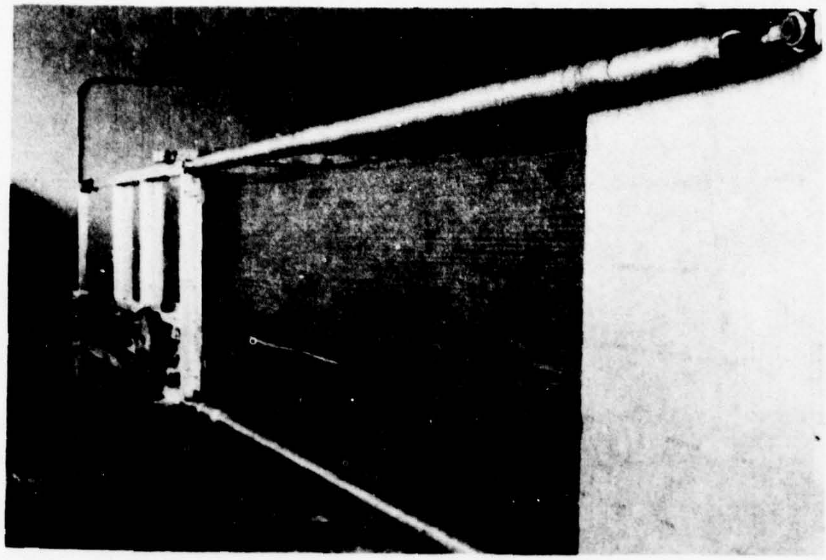


FIGURE 11. SIDE VIEW OF FIBERS DURING ASSEMBLY

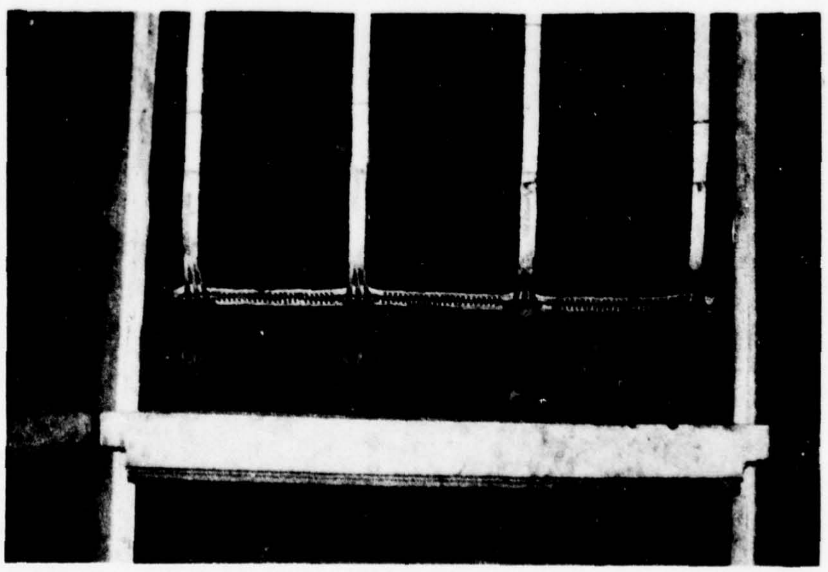


FIGURE 12. TOP VIEW OF BELT INSTALLED IN SKIMMER

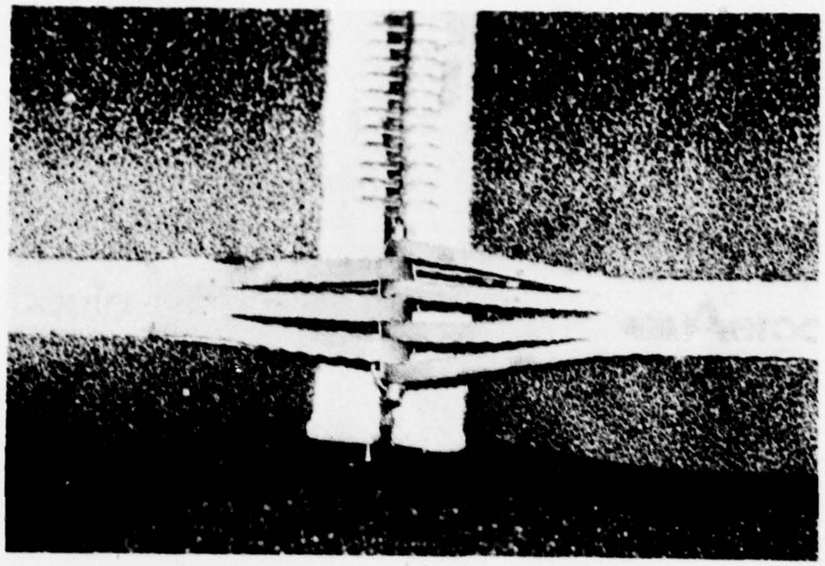


FIGURE 13. POLYESTER TENSION-STRAP JOINT FOR BELT

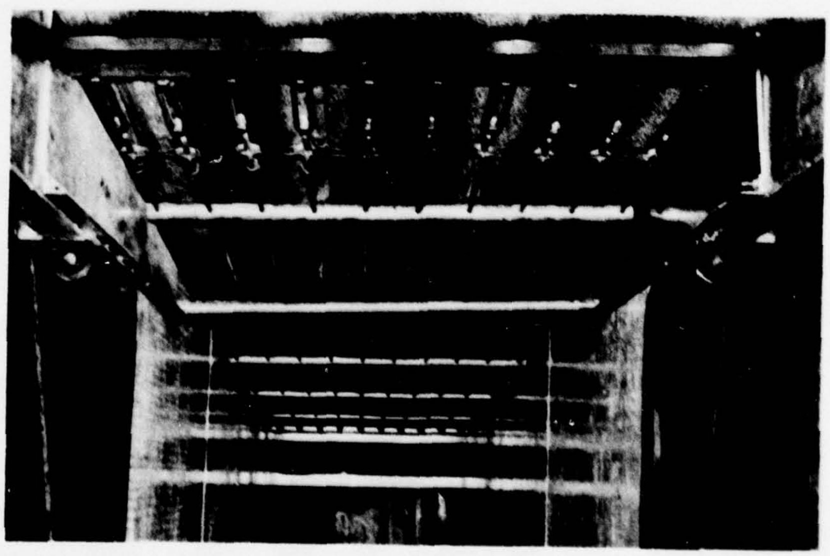


FIGURE 14. BELT SUPPORT CABLES

belt during operation, plastic-coated flexible cables were strung lengthwise beneath the top and bottom levels of the belt loop. Figure 14 shows the cables under the bottom level. The cross-tubes serve only to maintain proper spacing, and are not attached to the sides of the device. The belt was driven hydraulically by two motors, one on each belt roller. Figure 15 shows the front drive mechanism during assembly. At a belt speed of 5 fps, the theoretical capacity of the belt at 20 percent loading is 95 gpm.

3. Floating fiber supports: Both the front and rear fiber supports were supported independently by foam-filled plywood floats. Figure 9 shows the two front floats, which could be adjusted vertically to change the mean fiber depth in the water. The single rear float can best be seen in Figure 16 extending to the back wall of the skimmer. To reduce the weight that had to be floated, the sidewalls (next to the fibers in the picture) were designed to be fixed to the hull, with the turnbuckle arms and pivot arms located between the sidewalls and the hull. Both the front and rear supports could be lifted clear of the water using block and tackle arrangements.

4. Oil pickup head: A foam-filled lightweight aluminum box was used to float a plastic pipe/hose manifold, which took suction beneath the box to recover the oil. This arrangement is shown in Figure 17. The box was located above the squeeze roller between the rear fiber supports and the rear float, and was connected by pivoting arms to the rear float so that it could conform to the surface independently of the float. The weight of the four-inch pipe and hose leading to the pump (same pump as in the previous model) was borne by the rear float as shown in Figure 16 in order to minimize the draft of the pickup head. Foot valves were installed in each of the three openings to minimize oil back-flow between test runs.

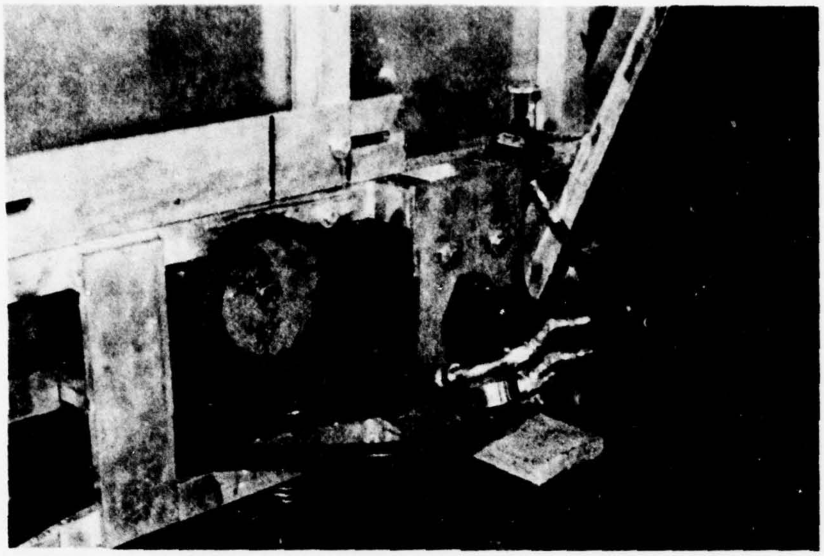


FIGURE 15. FRONT ROLLER DRIVE ASSEMBLY

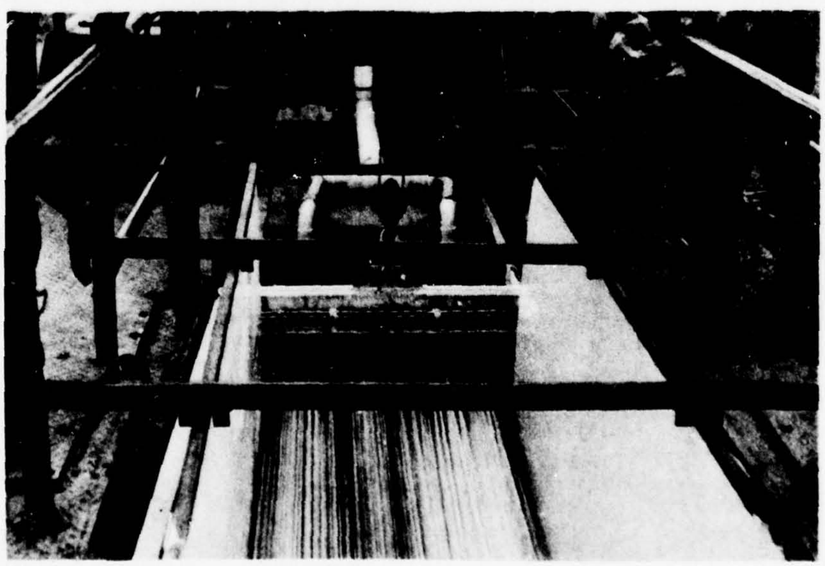


FIGURE 16. REAR FLOAT AND SIDEWALLS

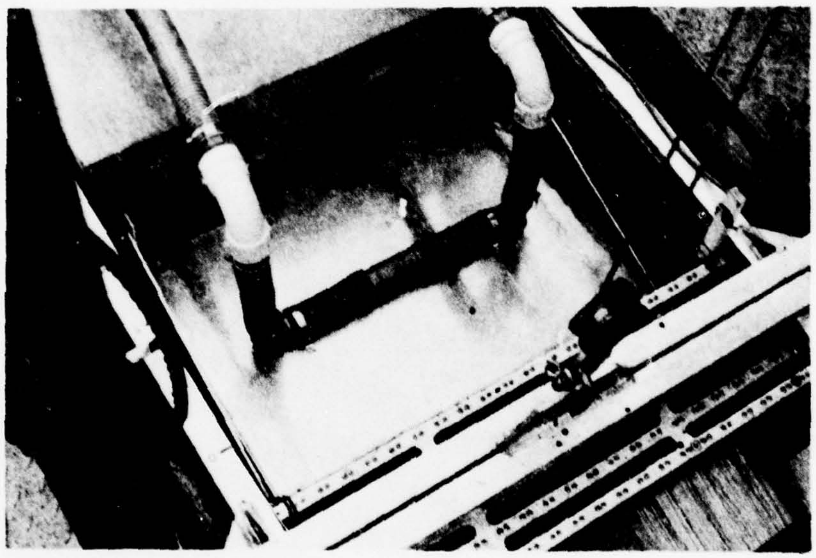


FIGURE 17. OIL PICKUP HEAD

5. Other features: To facilitate OHMSETT testing, a special gate was designed that could be dropped down in front of the fibers to trap oil in the device.

The basic hydraulic system was the same as that used in the previous model with modifications to operate the belt system. The squeeze roller was controlled by two hydraulic cylinders to maintain a squeeze force proportional to the tension in the belt. The belt could be tensioned by a separate cylinder to enhance the gripping quality of the Velcro drive strips.

The fiber and belt assembly was free to heave and pitch, but it was restricted in the other motions by the presence of the hull. To keep the assembly from contacting the rear of the hull opening, four parallel pivoting arms were attached between the forward part of the hull and the rear float assembly.

<u>Testing:</u> A test plan was prepared before the testing was begun. Details are given in the Appendix. The significant parameters that were to be varied are listed below:

1. Tow speed: The range from 2 to 6 knots was to be covered, with most of the tests in the 4 to 6-knot range.

2. Wave conditions: Three wave conditions were to be tested, including a 15.2-inch high by 19-foot long regular wave (2.0-second period), a 16.8-inch high by 35 foot long regular wave (2.5-second period), and a 2-foot "harbor chop."

3. Test oils: Oils to be tested included Circo X Heavy (Sunoco) with a 1400-cs viscosity at 66°F (0.944-sp. gr.), and Circo 4X Light (Sunoco) with an 8.9-cs viscosity at 66°F (0.888-sp. gr.).

4. Oil distribution rates: Oil rates of 56, 95, and 130 gpm were to be tested, representing approximately 60, 100, and 140 percent of belt capacity, respectively. (Belt capacity is explained on page 26). This represents a range in slick thickness of from 1.3 to 4.4 mm, within the speed range of 4 to 6 knots.

5. Device parameters: Variations in fiber depth, fiber/belt sag, and belt speed were to be examined to establish the best device settings for the bulk of the testing.

The results were to be expressed in terms of throughput efficiency, recovery efficiency, and oil recovery rate. Throughput efficiency was to be calculated as:

$$\text{Throughput efficiency} = \frac{\text{Oil encountered - Oil lost}}{\text{Oil encountered}} \times 100\% \qquad (3)$$

where the "oil lost" term is calculated as:

Oil lost = Initial oil inventory in device (precharge) + oil encountered - final oil inventory in device - oil recovered. (4)

This type of calculation, where all of the oil is accounted for, was used because of the difficulty in establishing steady-state conditions in a single pass down the tank. To reduce the impact of errors in the inventory measurements, three to five passes down the tank per data run were planned, thereby increasing the "oil recovered" and "oil encountered" terms in Equation 4 . At the end of each pass the inventory oil would be trapped in the fiber array and the skimmer slowly pulled back up the tank for the next pass.

Recovery efficiency was to be calculated as the average of the oil fractions in a series of discrete samples (taken at approximately 10-second intervals) that appeared to represent steady state. Recovery rate was then to be estimated as the recovery efficiency times the average flow rate from the skimmer recovery pump.

Testing was conducted during the period of 8 - 15 August, 1977.

Results: During the non-oil tests at the beginning of the test program, it became apparent that the foam belt would not track properly. One side of the belt tended to creep ahead of the other side, eventually pulling the other side off of the Velcro drive strip, and bunching the foam in between the rollers. The problem was not as severe at low belt speeds, and initial oil tests were planned for a 2-fps belt speed.

The first oil test was a check-out run, with no precharge and no pumping. The purpose was to check out the oil dispenser system and to pre-wet the fibers and belt. It is not certain if the belt was even turning during this run. The fiber array was then lifted clear of the water to drain out the oil, in preparation for the first oil run.

The first run, No. 1-1A (first pass) was in calm water, at a speed of 4 knots and a heavy-oil feed rate of 70 gpm. A 130-gallon precharge was used, and the belt speed was 2 fps. Observations of the tank surface behind the skimmer indicated only small losses, and a decision was made to increase the oil feed rate to 130 gpm on the next pass. On this pass, No. 1-1B, the belt tracked off to the side, and exposed a 6-inch gap along the side. Because this gap was probably a source of oil losses, a valid evaluation of the efficiency could not be made, and further passes were discontinued. Because of later difficulties, pass 1-1A turned out to be the only valid belt test in the entire test period. (Fiber depth was 12 inches and fiber sag was 6 inches.)

An underwater motion picture sequence labeled merely Run #1, indicated very little loss when compared to later runs made without the belt. The movie sequence immediately following this

one was labeled Run #1-1B (a surface sequence), indicating that the first sequence was actually number 1-1A. (This was also confirmed by OHMSETT's data sheet for run 1-1A.) Underwater video shots indicated a light cloud coming from the bottom, but much less than in later runs without the belt. It appeared that the belt did indeed improve performance, although to what quantitative extent it was not known.

While attempting to control the belt tracking by manual means, the belt snagged and tore. Later, a spare belt was fitted with a polypropylene mesh backing to give it stiffness and hopefully improve tracking, but this belt also snagged and tore.

Several tests were run without a belt, in calm water and in waves. In all cases it was apparent that performance was inadequate without a belt. All of these tests were conducted with only the heavy oil.

Runs were also made without oil to check out wave conformance. The floating front and rear fiber supports were shown to be effective in minimizing mismatch between the surface and the fibers. Due to structural limitations with the skimmer hull, not enough vertical fiber array excursion could be built into the system to handle the regular waves without "bottoming out" on the lower hull cross-beam. However, in 1-foot harbor chop, excursions were within the system limits, and conformance was good.

Whether slack fibers were effective in improving performance through better wave conformance, was not apparent. However, slackening the fibers did permit them to stick together easily, forming vertical "sheets," which probably detracted from performance. Whether these sheets remained as sheets below the surface during a run was again not apparent. One other inherent problem with the belt design was the blockage caused by the front roller. However, this problem could be minimized in a modified belt design.

Because both belts were damaged, and it was impossible to make adequate repairs or modifications in the time remaining, the test program was terminated on 15 August. A summary of possible courses of action was prepared, but no further tests were planned.

3.6 Belt Failure Analysis

The belt failure could be classified two ways:

1. When the belt pulled away from the sidewall, it exposed an area available for the oil to bypass the belt; this caused functional failure.

2. Physical failure occurred by tearing the foam itself, primarily at close-clearance points where the bunching together caused the foam to contact these points and jam; the drive strips, tension straps and connection joints were for the most part relatively undamaged.

The types of failures experienced at OHMSETT were not observed in flume testing. In the flume tests, the small-scale model belt was relatively stiff because of its narrow width, and therefore could maintain its shape in the presence of distorting stresses. The OHMSETT belt had been successfully tested in the shop during system assembly. However, even though the belt had been oil (SAE 20) and water soaked, no flow-induced loads could be applied to test the belt under operating conditions. Velcro-drive foam belts had been successfully used before in oil skimmers manufactured by the Marine Construction and Design Co., but the application in this case was considerably different.

The tendency for one side of the belt to creep ahead of the other during operation may have been due to several causes, such as:

1. Excessive drag on one side of the belt caused by fibers sagging more on that side.

2. Misalignment between the front and back rollers (this was checked and appeared to be satisfactory).

3. Difference in Velcro gripping characteristics from one side to the other in the presence of water and/or oil.

4. Framework misalignment caused by floating or handling.

5. Slight differences in the length of the tension straps.

6. Slight differences in diameter along the length of a given roller (doubtful, because the rollers were turned on a lathe).

By applying a braking action to the tension strap that was drawing ahead, the straps could be kept in line, and the belt would not pull away from the side. This was considered as a possible active control method, but because the operator could not see the belt when the fibers were lowered and the floating pickup head was in place, a viable control system would be difficult to incorporate.

Stiffening the belt in shear with a stiff backing screen was also considered and tried with some degree of success, but this approach had several drawbacks. First, the screen was subject to snagging, and this problem eventually caused the destruction of the spare belt. More significantly, the thickness of the screen would prevent the foam from being squeezed sufficiently, particularly when only a fifth of the belt thickness was useful in storing oil in the first place.

Conveyor belt techniques were considered, such as crowning the rolls to ensure tracking, but because the belt has no stiffness or strength except at the tension straps, such techniques were considered infeasible.

A positive belt drive system, using roller chain attached to the belt and sprockets, appears to be the best approach to ensure tracking. However, chain drives must be maintained fairly tensioned and the desired wave-conforming feature of the belt would have to be sacrificed to ensure proper engagement of the chain and sprocket. This was the basic approach recommended before the active work on the model was terminated, and is the approach taken in the preliminary prototype design presented in the Appendix.

4.0 CONCLUSIONS

1. The foam belt appears to improve performance of the system by trapping oil that escapes from the fiber array. The degree of improvement could not be determined, however.

2. The wave conformance of the fiber array was improved significantly by independently floating the fiber supports. However, without the foam belt, an improvement in oil skimming capability could not be achieved.

3. The anticipated benefits of slack fibers appeared to be negated by the tendency of the fibers to stick together in the presence of viscous oil. It could not be determined during OHMSETT tests whether or not the fibers conformed to the wave profile, even without the presence of oil, because the upper fibers (out of the water) restricted the visibility.

4. The front roller and/or the belt itself appear to make a significant contribution to the flow blockage at the front of the device. Improvements can probably be made here, but blockage alone may limit the concept to speeds in the 5 to 6-knot range.

5. The Velcro drive concept does not work satisfactorily with the foam belt system, because the belt will not track properly.

6. The oil retention capacity of 1-inch thick reticulated polyurethane foam appears to be constant at approximately 21 percent of the foam volume for viscous oils, short contact times ($<$10 sec), and water throughput velocities on the order of 1 fps or less; with light oil the retention appears to be a function of velocity, pore size, and probably interfacial tension (Weber number correlation).

5.0 RECOMMENDATIONS

As a result of analyzing the mechanical problems encountered at OHMSETT, it appears that to fully evaluate the concept of a submerged foam belt with a floating fiber array, significant modifications to the large-scale model would be required. These modifications would include:

1. Positive belt drive system (roller chain) on a non-wave-conforming belt.

2. Tensioned, non-wave-conforming fibers.

3. Replacement of the articulated turnbuckle-arm framework with a rigid framework to provide a more dimensionally-stable system for belt guiding and support.

4. Eliminate the cable supports for the belt and other potential sources of snags.

5. Improved design of the front roller, to minimize blockage effects.

These recommendations are developed further in the Appendix, where a design for a prototype skimmer, using the most promising fiber system technology is presented.

6.0 REFERENCES

1. Beach, R. L., F. A. March, "Development of a Streaming Fiber Oil Spill Control Concept," Final Report to the Coast Guard, Report No. G-D-35-75, Contract No. DOT-CG 40,217-A, March 1975.

2. Beach, R. L., D. W. Durfee, R. J. Powers, "Development of a Streaming Fiber Oil Spill Control System, Stage II," Final Report to the Coast Guard, Report No. CG-D-4-77, Contract No. DOT-CG-40217-A, December 1976.

3. Moses, R. O., and Sandra Blackstone, "Fiber Belt Oil Recovery System," Final Report to Coast Guard, Report No. CG-D-82-74, Contract No. DOT-CG-14,058-A, December 1971.

APPENDIX A

PRELIMINARY DESIGN OF A FULL-SCALE PROTOTYPE SKIMMER

1.0 INTRODUCTION

Presented in this section is the preliminary design for a full-scale prototype oil skimmer. In this design, the basic principles of the streaming fiber concept, information developed in previous design work, and knowledge gained from OHMSETT testing are brought together to formulate a unified approach to a feasible and practical oil skimming device.

Because of the inconclusive nature of results from OHMSETT testing, it is still unclear whether or not this type of device could meet the original design goals as specified by the Coast Guard and listed in Table A-1. Should the project be carried further, additional OHMSETT testing should be performed to verify the capabilities, identify the weaknesses, and further develop the operating parameters in this type of system, before the tasks of detailed prototype design and construction are undertaken. Before testing is performed at the OHMSETT test tank, the system should be thoroughly checked out and "debugged" through operational "sea trials" (without oil) in a harbor or other convenient location.

This preliminary design is presented in very basic form, primarily to preserve the knowledge gained thus far in the project and to present our latest conceptual aims for future development. The primary emphasis is placed on the oil recovery system and the debris protection system, with less emphasis on the aspects of air transportability, powering, naval architecture, and auxiliary systems.

TABLE A-1
FAST CURRENT OIL RECOVERY
DESIGN GOALS

Areas of Operation

A. Bays, Harbors, Estuaries
B. Coastal Rivers
C. Coastal Waters

Operational Environment

Up to 6 knots current with optimal recovery in the 2 to 4-knot range and 2 feet confused sea with 20-knot winds.

Survival Environment

with current

A. 15 knots current with calm seas
B. 10 knots current with 4-foot waves and 20-knot winds

moored or adrift

A. 6-foot wave height with 40-knot wind for one week

Minimum Oil Thickness

0.04"

Oil Type

Complete range of oils including distillate fuel oil, residual fuel oil, and crude oil with optimum recovery to be in the range of 10 cs to 500 cs.

Sea Temperature

+28°F to 100°F

Air Temperature

0°F to 120°F

Mode of Operation

Moored, towed, and self-propelled

Transport from Central Storage to Nearest Port

One C-130 (39' x 9' x 7'10" LWH
with a maximum weight of 25,000 pounds each)

(Table A-1 continued)

Transport from Nearest Port to Scene

A. Self-propelled
B. Towed by CG or commercial vessel equal to or greater than a CG 82-foot WPB
C. Carried on deck of CG 180-foot WLB or a comparable commercial vessel

Power Supply

Included

Fuel Supply

12-hour endurance

System Integrity

Impervious to the environment and oil

Cleanability

Easy to clean

System Support

A. Simple to assemble, install, load, launch, tend, refuel, maintain, operate, repair, and retrieve
B. Reliable
C. Assembly to be accomplished on scene in two hours

Control Function

System shall be capable of controlling oil so that it can be recovered.

Recovery Function

A. Throughput Efficiency $\geq$ 95%
B. Recovery Efficiency $\geq$ 75%
C. Recovery Rate up to and including 300 gpm

Debris Handling/Protection Function

Shall be able to handle a moderate size and amount of debris.

Pump and Transfer Function

Pump up to 300 gpm and not emulsify the oil.

Temporary Storage

Temporarily store 1400 gallons aboard and 500 long tons by external means.

2.0 DESIGN SUMMARY

Because of the operational problems encountered at OHMSETT, the test results were inconclusive in determining the effectiveness of the independently-floated, belt-assisted system. We still feel, however, that the basic streaming fiber concept is sound, and that the independently-floated fiber array, foam-belt system, and floating oil pick-up head are essential to the improved performance of the device over a wide variety of operational conditions.

The principles of operation employed in the proposed prototype design are basically very similar to those of the 1977 large-scale OHMSETT model. Parallel streaming fibers, made of nylon monofilament, are used to gradually slow down the flow of incoming oil and water. As the flow moves toward the rear of the device, the oil layer tends to increase in thickness and the water and any entrained oil flows out through the bottom of the fiber array. The entrained oil is filtered out of the water flow as it passes through an oleophilic porous foam belt rotating immediately below the fiber array. The belt carries the absorbed oil to the rear of the device where it is squeezed out. Released oil then floats to the surface of the collection pool where it is picked up by the floating pick-up head, along with any oil collected there by natural thickening.

The skimming mechanism, including the fiber array, side and back walls, belt system, oil collection area, and debris protection system, is independently-floated between the catamaran hulls of the skimmer vessel, supported by separate front and rear floats. This allows for better wave conformance, reducing the turbulance and resulting oil entrainment caused by relative vertical motion between the oil-water interface and the horizontal streaming fibers.

There are several basic differences between this preliminary prototype design and the OHMSETT test model. These changes are based on knowledge gained during OHMSETT testing, and involve trade-offs made to arrive at a more mechanically reliable and simplified design. Figure A-1 shows a simplified overall top view of the proposed prototype.

The most significant design changes result from compromising somewhat on the wave conformance of the device. While the independently-floated aspect of the design remains, allowing for a certain degree of wave conformance for the array as a unit, both the belt and fibers are tensioned and rigidly supported within the framework of the skimming center-section. This allows for a much more reliable and rugged design.

The belt support and tensioning systems have been greatly simplified. The complex turnbuckle-arm mechanism of the OHMSETT model has been replaced with a rigid light-weight framework and integral side-panel construction to support the fiber array and belt system. A set of rubber side-rollers guides and absorbs side loads between the skimming center-section and the inside walls of the catamaran hulls. Two main roller-pivots, rolling vertically in guide channels recessed into the catamaran hulls, translate longitudinal forces to the skimming section.

The debris protection system, mounted at the mouth of the skimmer, consists of a debris grill, manually activated rake, debris collection tray, and sweeper cart. This system allows debris to be picked up, raked up onto the collection tray, and swept off the tray to either side of the skimmer. The system is manually operated, relatively simple, light-weight, and easily removable.

The design of the fiber bar mounting plates has been changed to allow for rapid replacement and individual tensioning of the fiber bars.

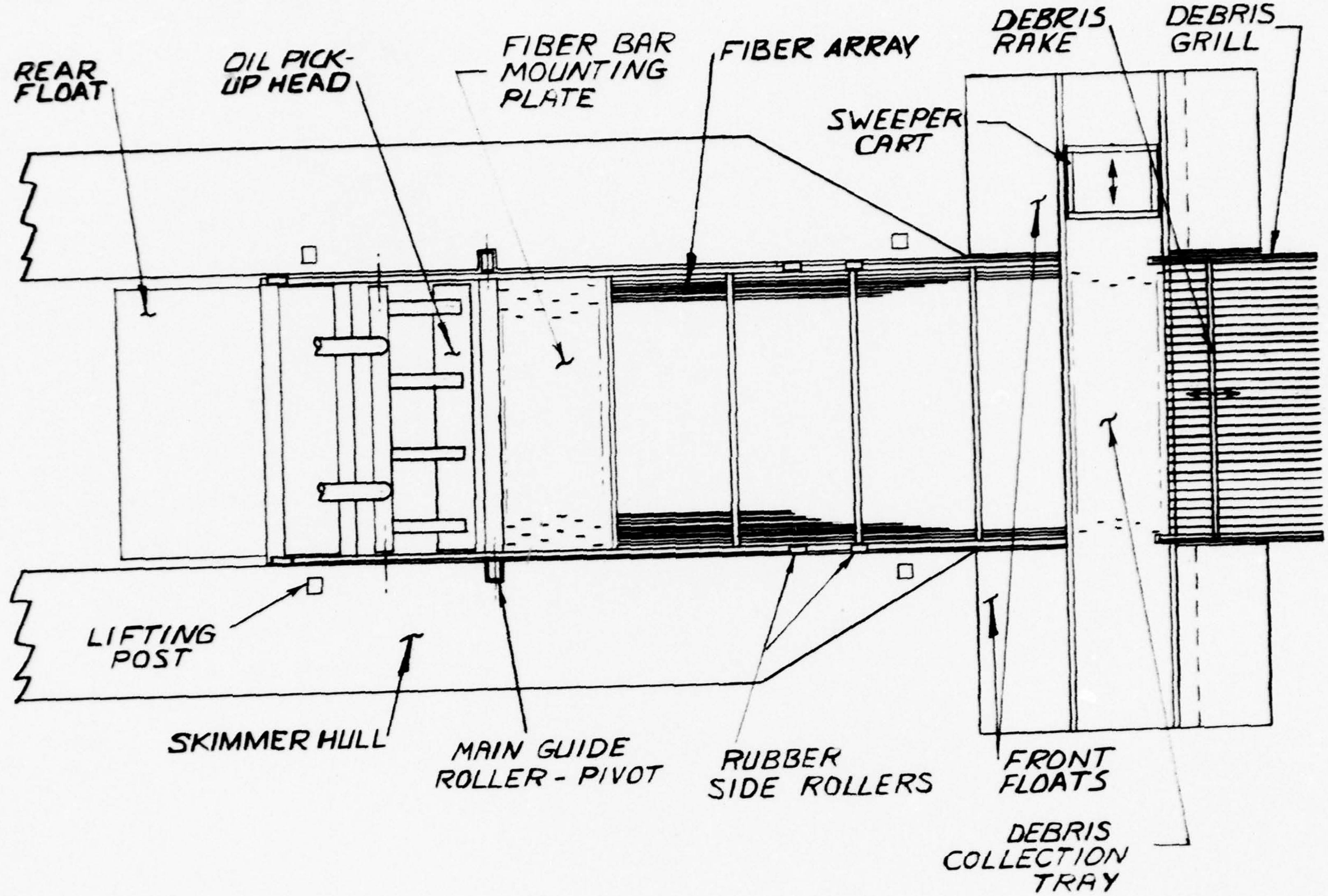


FIGURE A-1. SKIMMER AND HULL ASSEMBLED (TOP VIEW)

The proposed belt system employs a chain drive system, with replacable foam center-sections, and actually employs four adjacent belts. This provides for improved belt tracking and drive, and also allows for more rapid and inexpensive replacement of damaged or worn foam belts.

The skimming mechanism is supported by an aluminum catamaran vessel which can be disassembled and transported along with the necessary auxiliary equipment in a C-130 aircraft. The vessel contains two diesel-driven propulsion units, one in each demihull, which are capable of propelling the assembled hull at ten knots with the skimming mechanism raised out of the water. The catamaran is also outfitted with oil transfer pumps, storage tanks, hydraulic power system, controls, and necessary auxiliary equipment. The system weight, when packaged for air transport, is estimated at 25,000 pounds.

The basic subsystems summarized above are discussed in more detail in the following sections.

3.0 BASIC SUBSYSTEMS

The following sections describe in further detail the principles of operation and design for each of the major subsystems of the prototype skimmer.

3.1 Oil Skimming Mechanism

A drawing showing the main features of the skimming mechanism is shown in Figure A-2. All components of the skimming mechanism are, within cost limits, designed for adequate strength with minimum weight, as desirable for purposes of wave conformance. The various features are described below.

3.1.1 Streaming-Fiber Array

The fiber array is an integral part of the oil skimming mechanism. The fibers are nylon monofilaments, with a nominal diameter of 0.015 inches, and a breaking strength of approximately 15 pounds. They are continuously wound around sets of two 26-inch long by 1 by 1/8-inch vertical fiberglass bars spaced 15 feet apart, with a nominal spacing along the bar of 0.145 inches. Each bar is sheathed in a light-weight, extruded, plastic sheath which is bonded with adhesive to the bar. The fiber bars are held in a matrix providing a uniform fiber spacing of 0.145 inches horizontally, as well as vertically. The pattern of the matrix is identical to the OHMSETT device, except that the longitudinal spacing between rows of fiber bars has been increased by 50 percent. The fiber support plate is perforated and slotted for fitting of the fiber bars. Each bar has unsheathed smooth ends at top and bottom. Figure A-3 shows the fiber bar and support plate construction. A hole at the top of the bar allows a clip-ring to be installed, which holds the bar in place. This design allows for easy removal and replacement of fiber bars and allows the tension in each fiber bar to be individually adjusted. To remove a

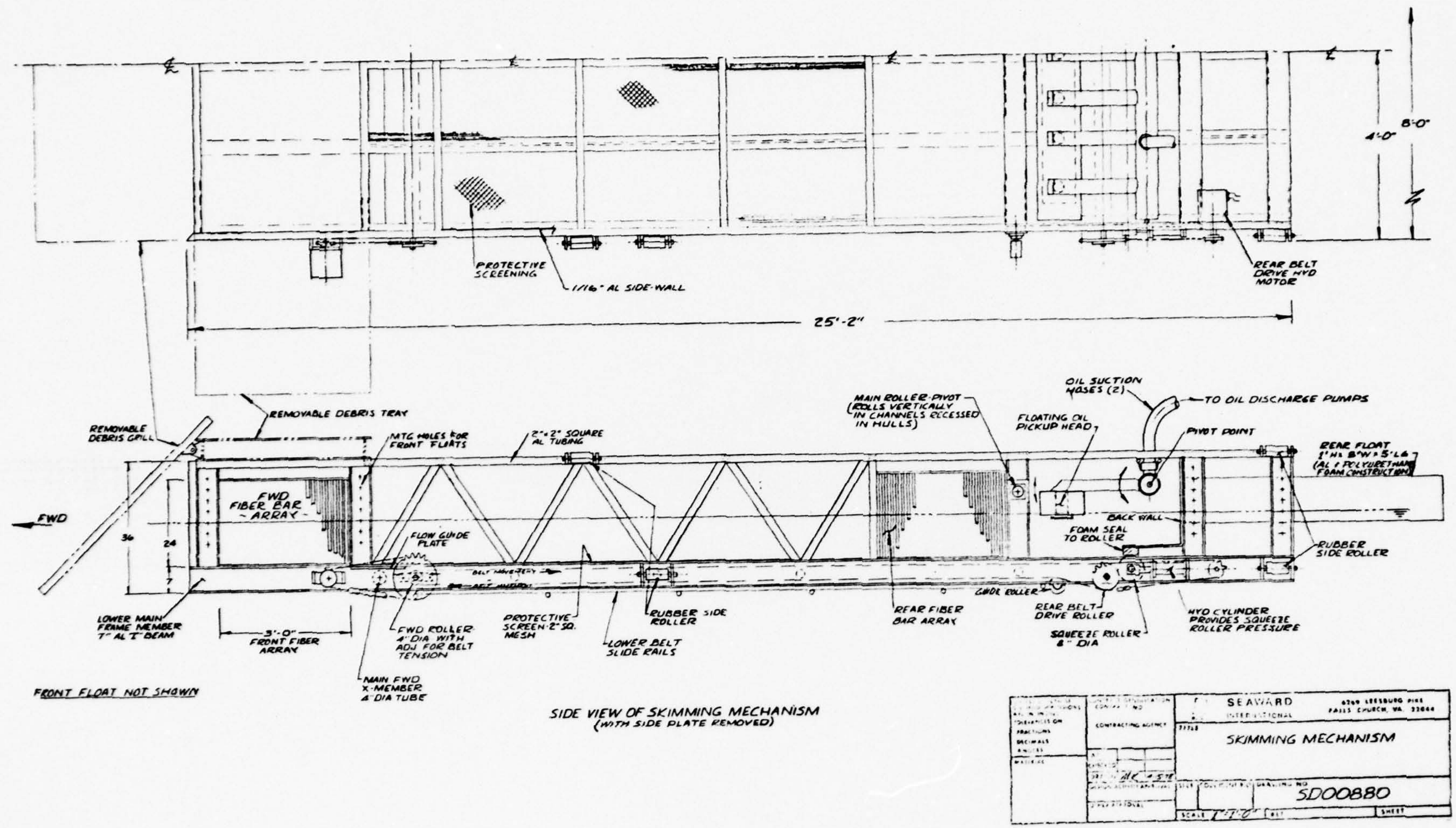


FIGURE A-2. SKIMMING MECHANISM

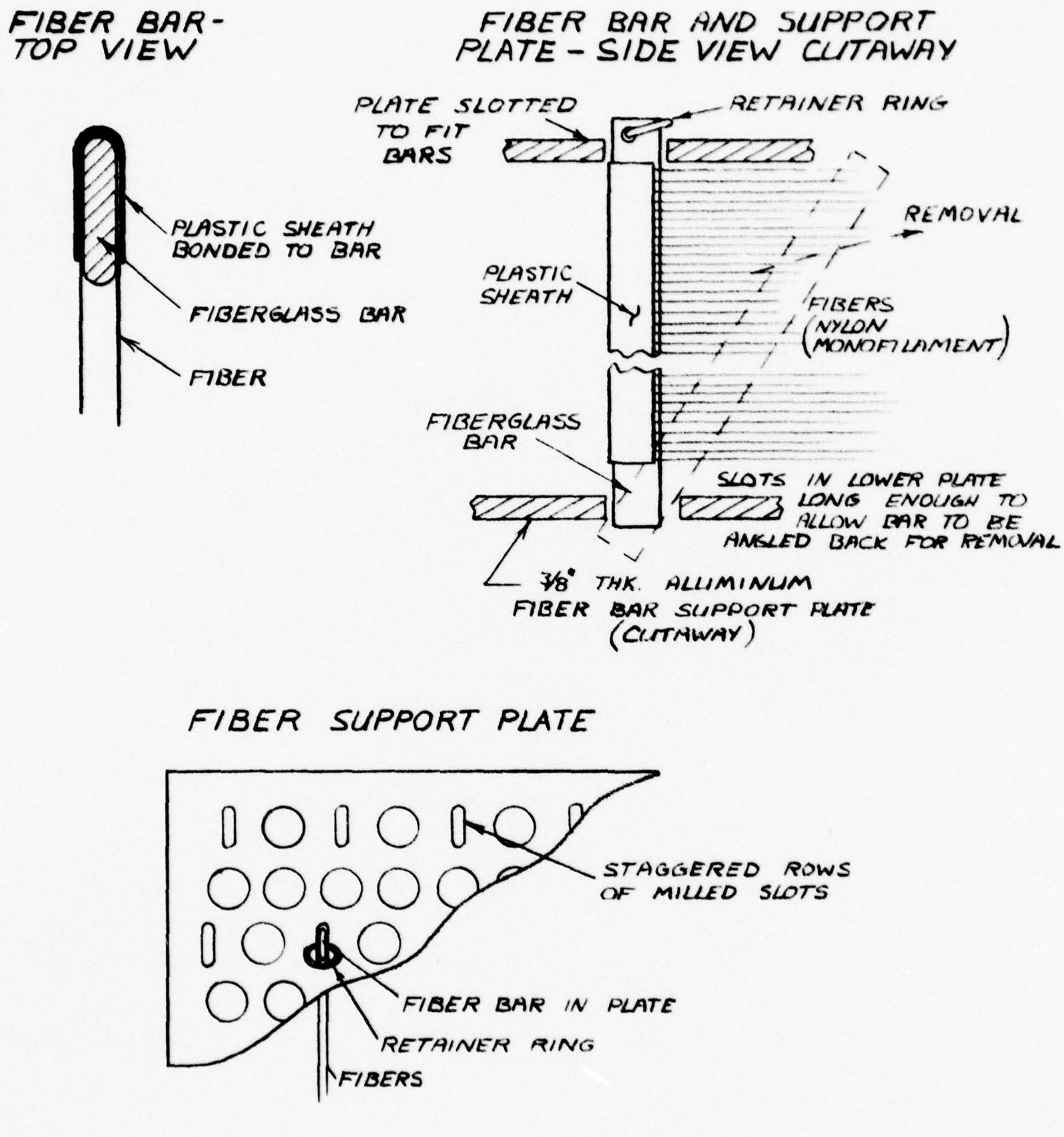


FIGURE A-3. FIBER BAR AND SUPPORT PLATE CONSTRUCTION

fiber bar the retainer clip can be simply removed; the bar can then be moved downward, angled back, and pulled out. Any fiber bar can be removed and rotated (wrapping or unwrapping the fibers around the bar) as necessary to adjust the fiber tension, and then be reinstalled. This design also has advantages in reduced weight and reduced hydraulic blockage to oil and water flow. For gross adjustment of fiber tensioning the rear fiber bar support plate can be moved relative to the framework.

3.1.2 Structural Framework

The fiber array, belt system, and oil collection area is enclosed on both sides and back by a light-weight aluminum-panelled structural framework. The front floats (not shown in Figure A-2) and rear float attach directly to this framework. The tranverse channels of the debris protection tray bolt directly to the framework and provide additional strength and stiffness to the mounting of the front floats. The main longitudinal strength members running lengthwise along the bottom are seven-inch aluminum I-beams. These support the belt drive and slide-rail support system. A two-inch square mesh between the fiber array and moving belt prevents entanglement and damage to the fibers. A set of rubber side-rollers and two main roller-pivots, riding vertically in recessed channels in the catamaran hulls, guide and limit movement of the skimming mechanism between the hulls.

3.1.3 Belt System

As in the OHMSETT test model, the purpose of the moving sorbent belt is to trap entrained oil droplets as water flows through the belt and out the bottom of the device , and transport absorbed oil to the rear of the device, where it is squeezed out and collected. Although this is a fairly complex system, it appears necessary for improved performance of the skimmer. A schematic showing the belt system operation is shown in Figure A-4. Because the principles of operation are identical to those of the OHMSETT

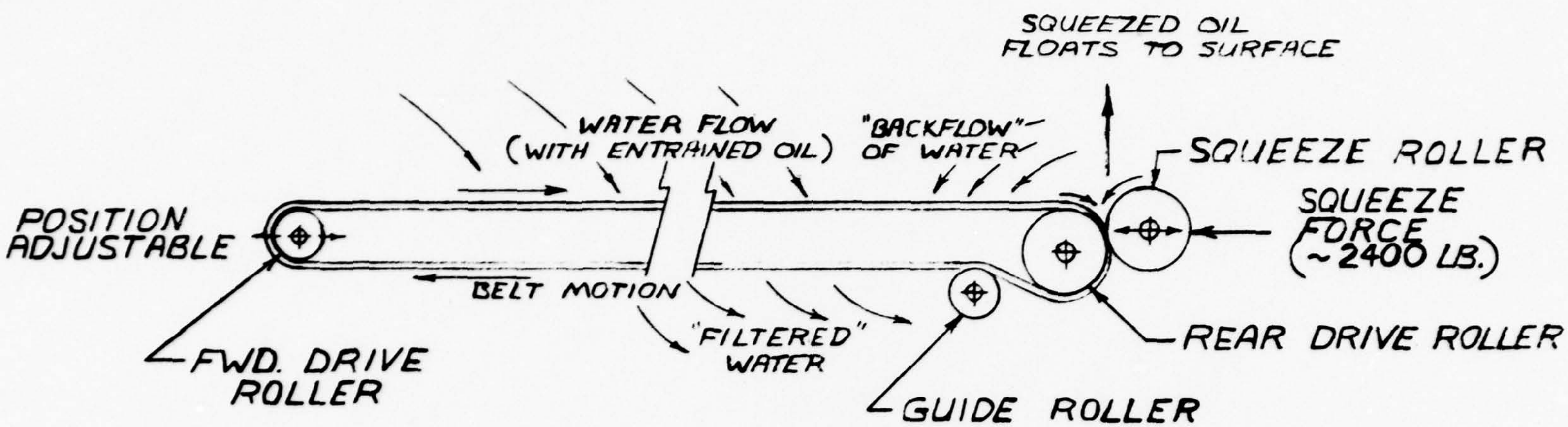


FIGURE A-4. SCHEMATIC OF THE BELT SYSTEM OPERATION

model, they will not be further discussed at this point.

An end view of the proposed belt construction is shown in Figure A-5. The belt system actually uses four separate narrow belts, rather than a single wide belt. This reduces shear force and side loading on the foam, and also facilitates belt maintenance and replacement. The foam portion of the belt is 10 p.p.i., reticulated, urethane foam. Stitched sandwich-style along the longitudinal edges of the belt, polyester cargo strapping provides strength and attachment points for the stainless steel drive chains. These conveyor-type roller chains have single side-tab attachment points every six inches along their lengths, and are attached to the cargo strapping by means of nylon stab-on fasteners. The stab-on fasteners simply snap into holes in the side-tab attachments of the chain. They provide excellent shear strength and facilitate rapid assembly or replacement of the foam belts.

When one of the foam belts needs replacement the expensive stainless steel drive chain can be easily salvaged and reused. Because all belt drive chains have to be equal in length, all chains should be replaced at the same time. The ends of the belt are reinforced with cargo strapping and are joined with standard belt lacing (low profile Clipper-type lacing), the chains being connected with master links.

The belts are driven at speeds of up to five feet per second by two hydraulically-driven drive rollers, one at the front of the device, just behind the lower, front fiber bar support plate, and one at the rear of the device, below the oil collection area, as shown in Figure A-2. Tensioning of the belt is manually adjusted by repositioning the front drive roller bearing blocks as necessary. The construction of the front drive roller is shown in Figure A-6, and the rear drive roller in Figure A-7. The front drive roller is small in diameter (4-inch O.D.) in order to keep flow blockage to a minimum. Both rollers have steel drive sprockets and are very

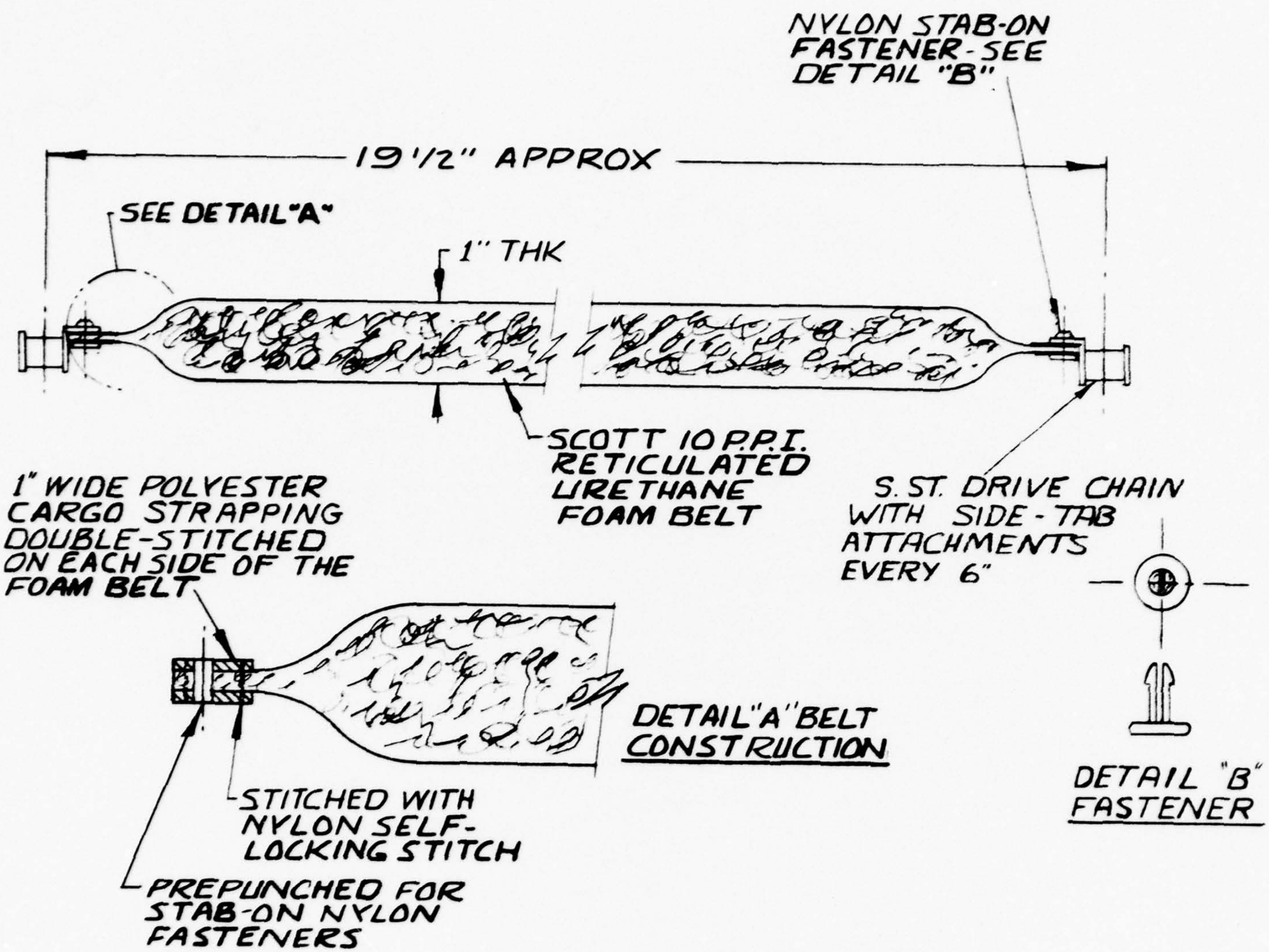


FIGURE A-5. BELT CONSTRUCTION (END VIEW)

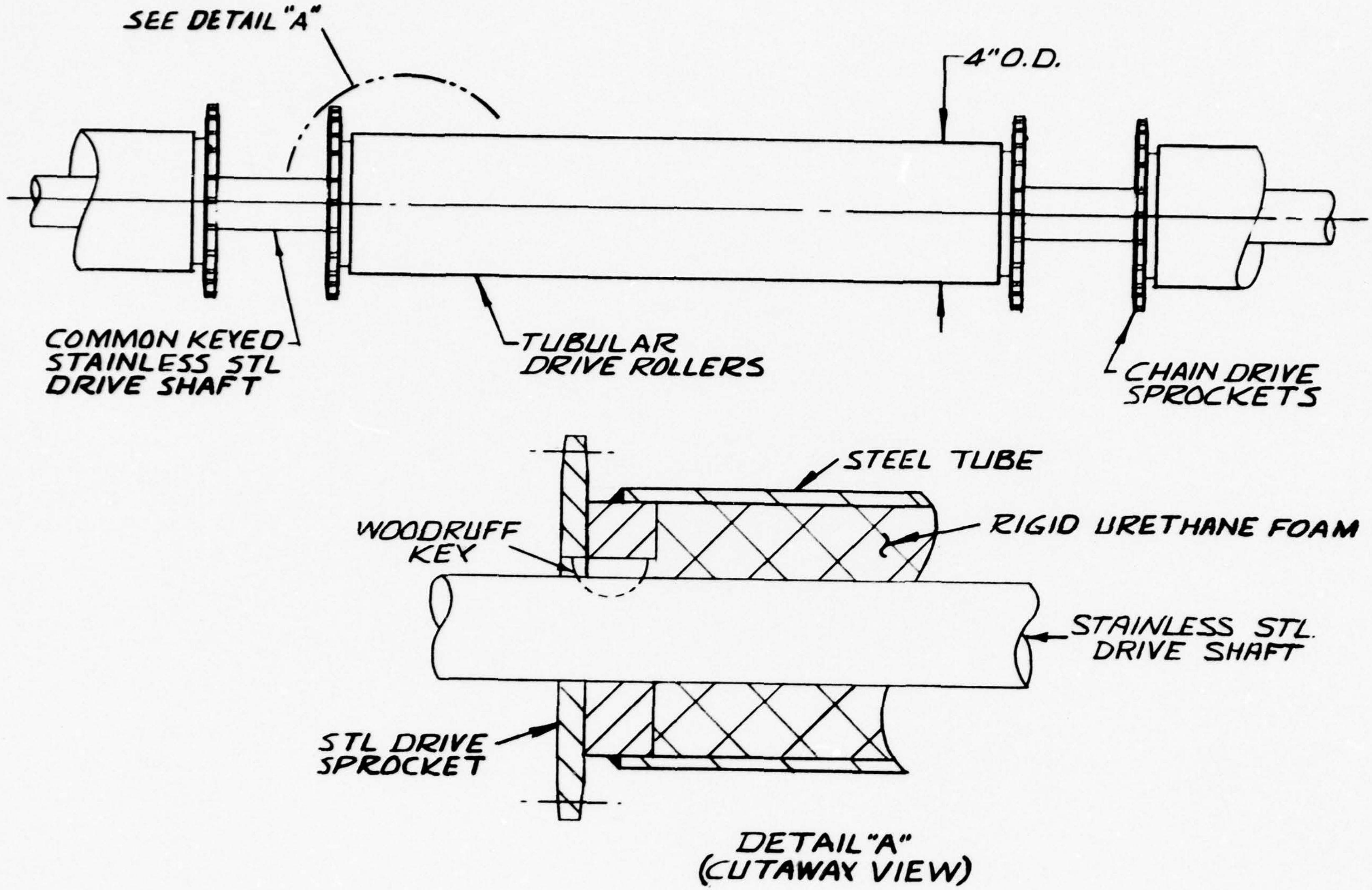


FIGURE A-6. FRONT DRIVE ROLLER CONSTRUCTION

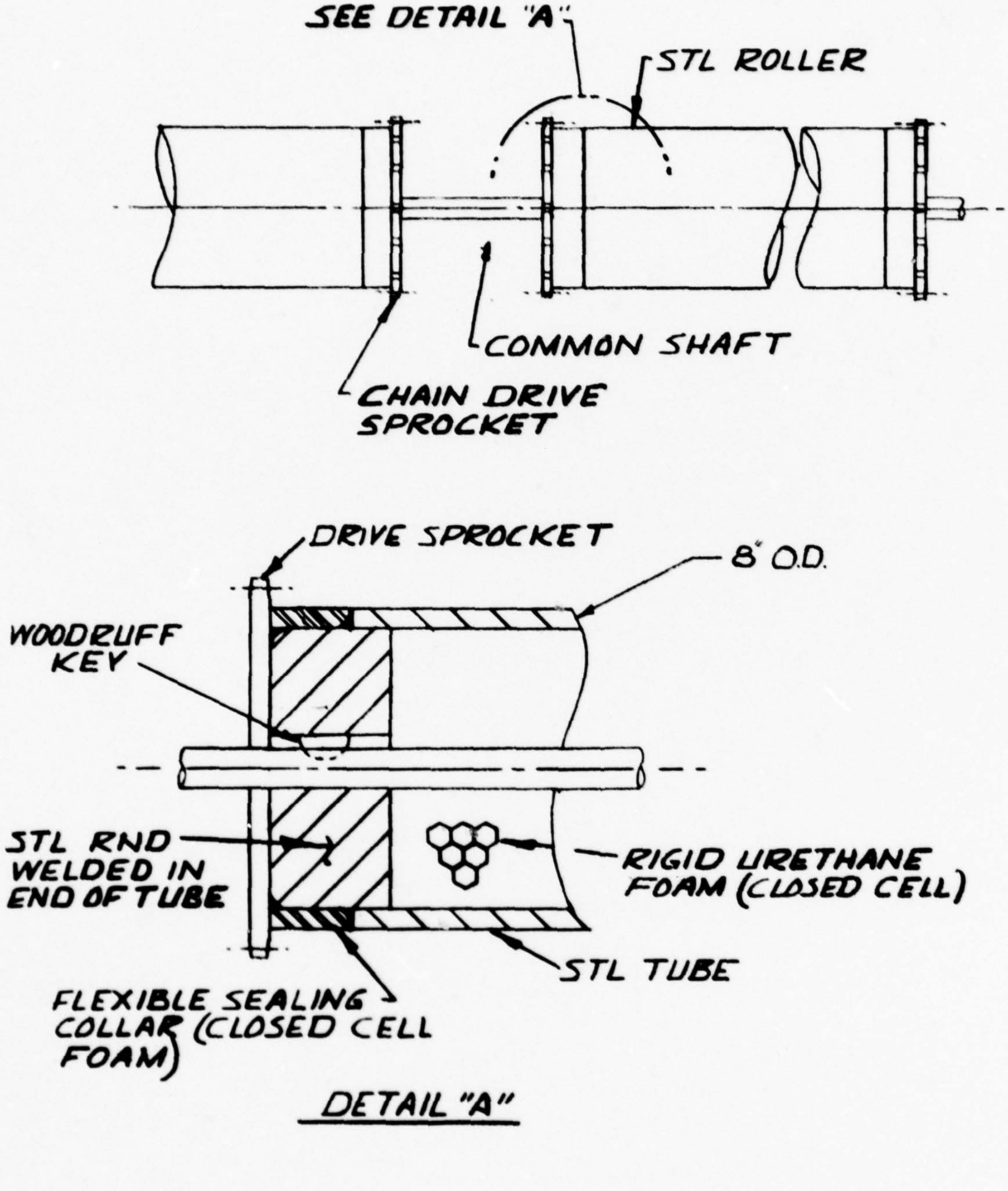


FIGURE A-7. REAR DRIVE ROLLER CONSTRUCTION

similar in construction. The rear roller is larger in diameter and differs from the front primarily in that it employs flexible foam sealing "collars" filling in the recessed areas between the sprockets and rollers. The purpose of these foam collars is to prevent oil, squeezed out of the belt at the rear of the device, from escaping between the rear roller and the squeeze roller.

The squeeze roller construction is shown in Figure A-8. This roller, unlike the drive rollers, is continuous in length and is covered with a 1/2-inch thick layer of low-durometer elastomer for protection of the foam belt. The squeeze roller is mounted on slide-block roller bearings and is hydraulically forced against the rear drive roller. Squeeze force (normally set at 2400 lbs) can be varied by controlling pressure on the squeeze roller hydraulic cylinders. For belt changing operations, the squeeze roller can be retracted several inches.

The squeeze roller, as well as the rear drive roller, is large in diameter (8 inches), in order to minimize internal pore pressure generated in the foam during squeezing. Foam seals eliminate all potential oil leakage paths between the squeeze roller, drive roller, frame structure, and sidewalls.

Immediately forward of the rear drive roller, a guide roller deflects the belt path upward, bringing it level with the forward drive roller. The construction of this roller is identical to that of the forward drive roller. Neither the squeeze roller nor guide roller are powered.

The lower frame members and belt support structure are such that the foam belts are completely supported and enclosed along their entire length of travel. A front cut-away view of the belt system is shown in Figure A-9. Immediately below both the upper, and lower belt paths, sets of longitudinal one-inch diameter slide rails (spaced three inches between centers) prevent the belts from sagging under load. All cross-members are located

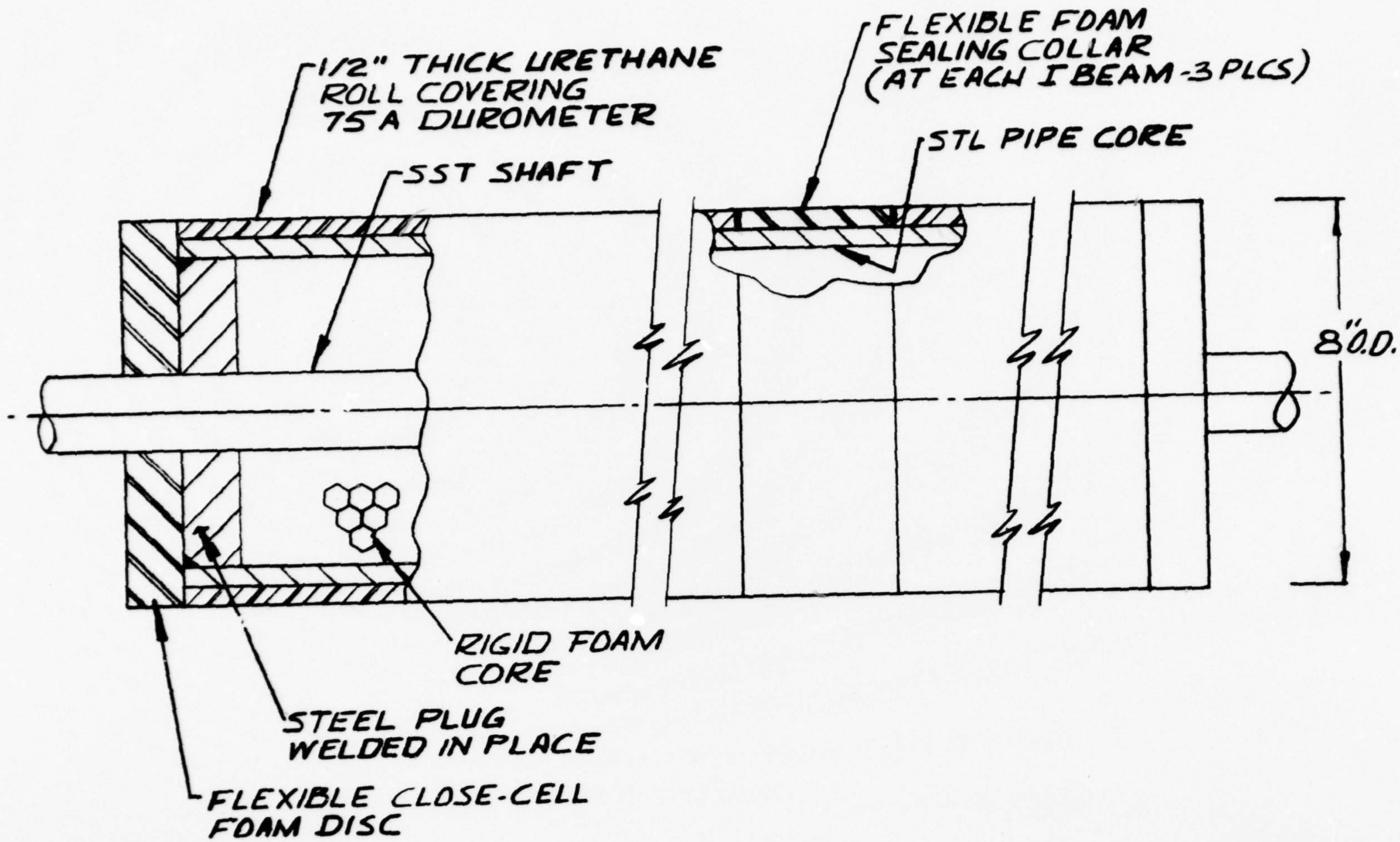


FIGURE A-8. SQUEEZE ROLLER CONSTRUCTION

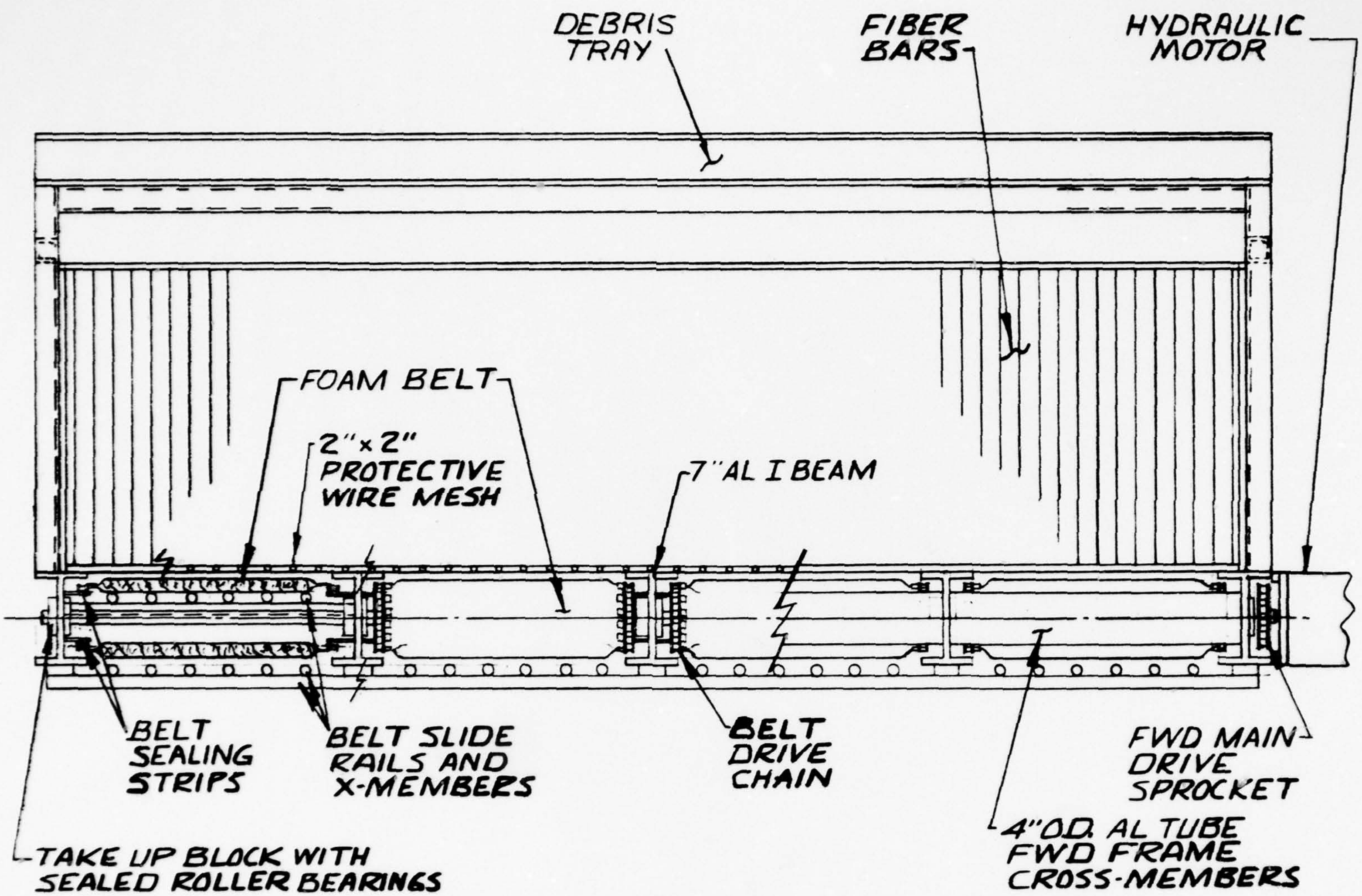


FIGURE A-9. FORWARD BELT DRIVE SYSTEM (CUTAWAY)

so as not to contact the belt. For access to the belts, the belt support structures are easily removable. Belt sealing strips welded to the seven-inch I-beams help to guide the belts and block off potential paths of flow leakage. All frame members, joints, and belt support structures are shaped and located to prevent snagging of the belts. A flow guide plate between the forward fiber bar array and forward drive roller guides flow over the roller. The belt is guided and sealed such that all water flow through the device is forced through the foam portions of the belts; all leakage paths are sealed.

3.1.4 Oil Collection Area and Floating Pickup Head

The oil collection area, at the rear of the skimming mechanism, provides an area for oil settling out and collection. Here the oil flowing through the fiber array reaches a standstill, and droplets of oil squeezed from the foam belt rise to the surface, forming a stable pool of oil. Due to the tremendous quantity of water that is squeezed out of the foam belts during operation, and the resulting forward water flow, the maximum thickness of oil generally forms at the forward end of the collection area.

A floating suction head is placed to pick up the floating oil. Because the pickup head floats at the surface it is unaffected by slight liquid level changes within the collection area. The construction of the oil pickup head is shown in Figure A-11. The pickup head employs seven 4-inch diameter vertical suction tubes and a large horizontal flat-plate baffle for even pickup distribution. The boxlike floating pickup head is attached to a lightweight aluminum manifold assembly which pivots off, and is supported by the sidewalls of the collection area. Two 4-inch I.D. flexible suction hoses connect this manifold to the piping of the oil transfer pumping system.

3.1.5 Floats

The two front floats and single rear float are constructed

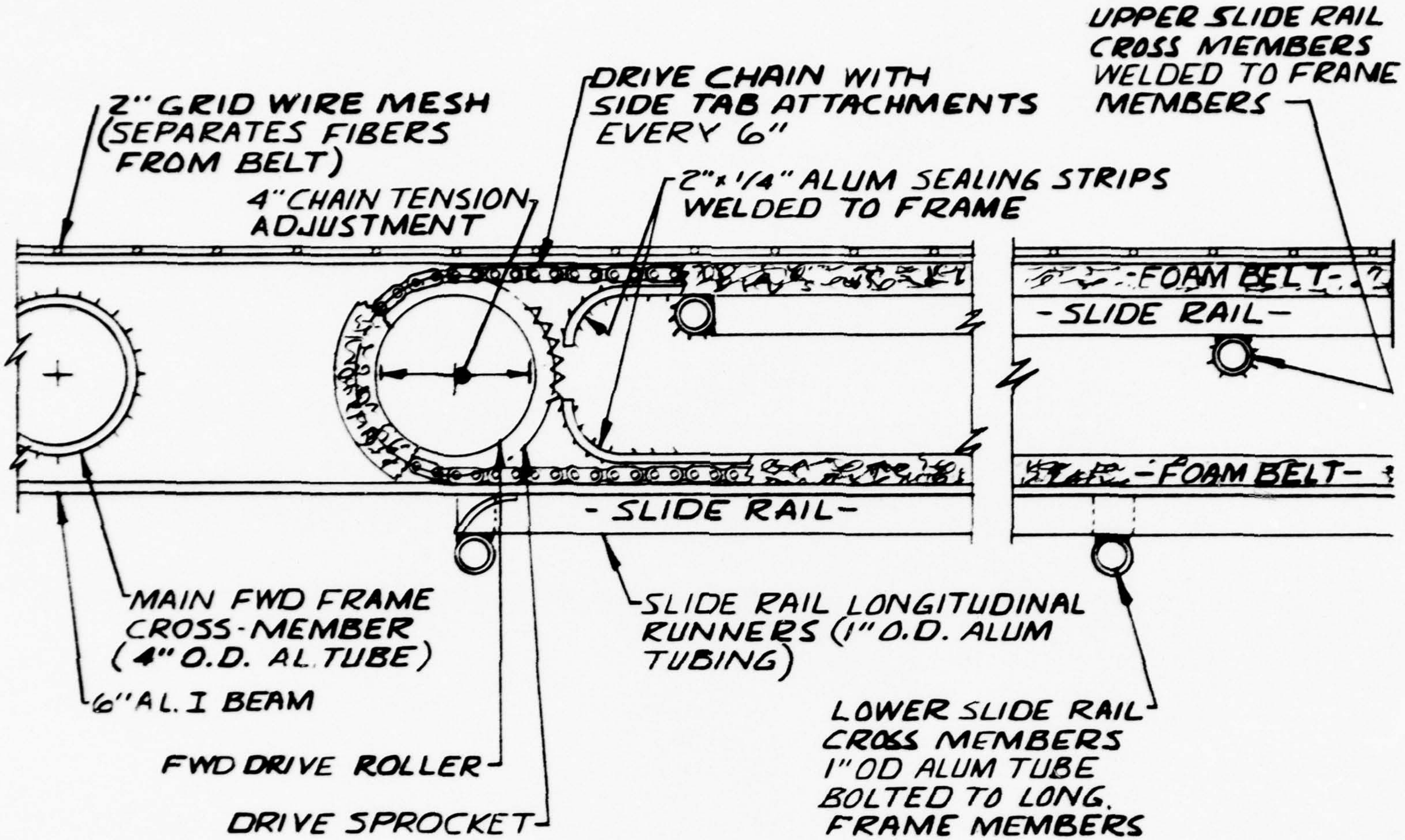


FIGURE A-10. BELT SYSTEM (SIDE VIEW CUTAWAY)

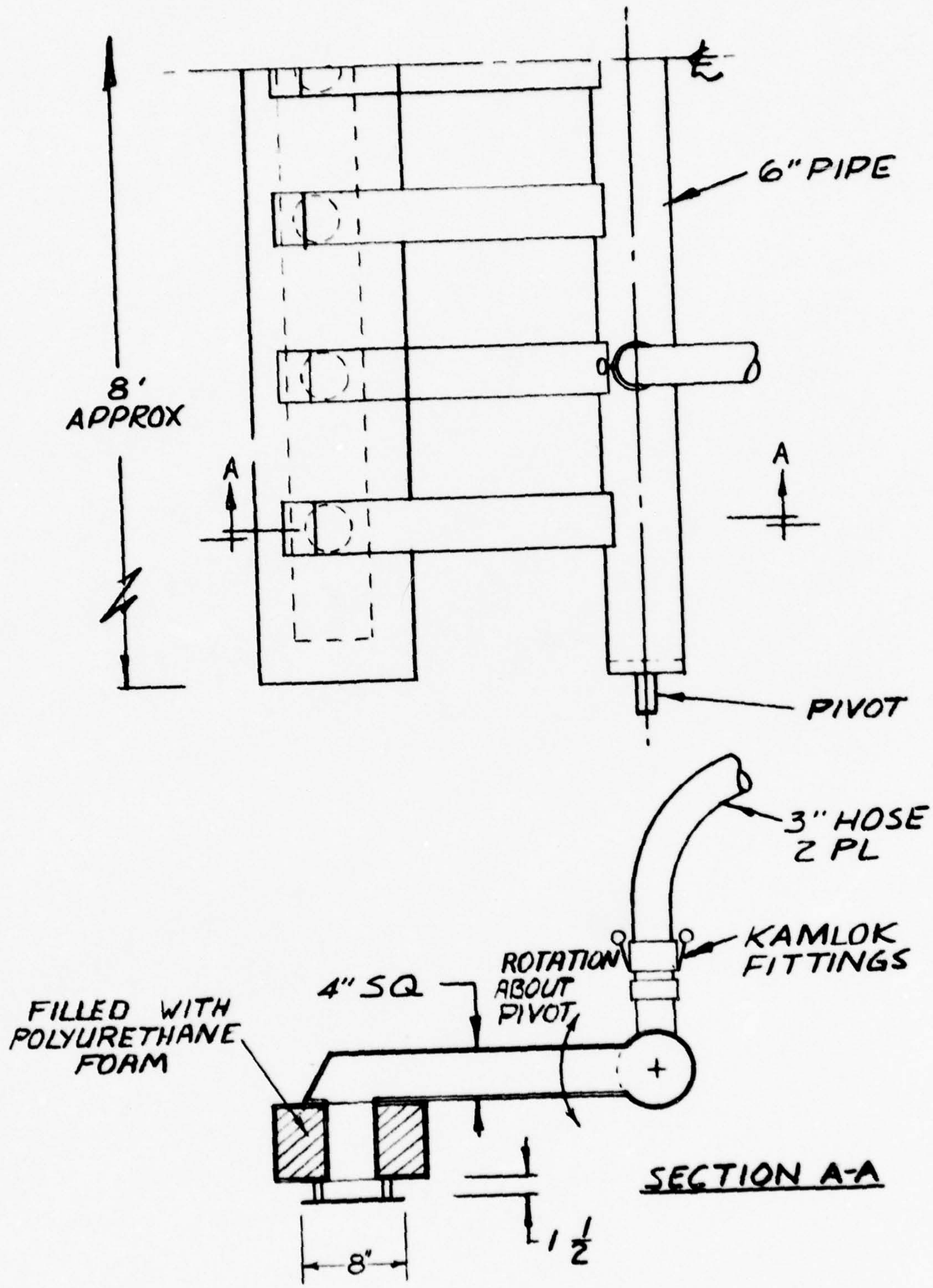


FIGURE A-11. OIL PICKUP HEAD

of 1/16-inch thick aluminum sheet, reinforced with a light-weight aluminum tubing framework, and filled with rigid polyurethane foam (closed cell, density approximately 2 lb/ft^3). All floats are approximately 5 by 8 by 1 foot high. The final design dimensions may vary, depending on more accurate final weight and dynamic loading calculations. The leading plane surfaces of the final floats are raked back at a 60° angle for optimum lift at higher skimming speeds. All floats have built-in mounting plates for attachment to the skimming mechanism frame and debris tray side channels. Attachment points on the front floats also provide for support of the removable debris grill.

3.2 Debris Protection System

Reliable and efficient debris removal is necessary at all times during skimmer operation, for adequate protection of the fiber array and foam belt system. The proposed debris protection is relatively simple, light-weight, and easily removable for more compact storage. The basic layout of the debris protection system is shown in Figure A-12.

Mounted at the mouth of the skimmer, between the front floats, a "debris grill" catches and picks up small, floating debris. The vertical slats of the grill are spaced 2 inches apart. Paired slats are 1/4-inch thick by 2-inch aluminum strip stock, for minimal flow blockage, while every third bar is 3/8-inch thick for additional strength in stopping larger debris. For protection against very small debris, a set of easily replacable, stainless steel, piano wire grill members are strung on 1/2-inch centers. These wires are located behind and are protected by the aluminum grill slats, normally contacting only the smallest debris. The debris grill is immersed the full depth of the skimming mechanism. It is raked back at a 45° angle from vertical. This causes the water flow and wave action to naturally push debris up the incline, keeping debris near the surface and minimizing blockage to entry flow.

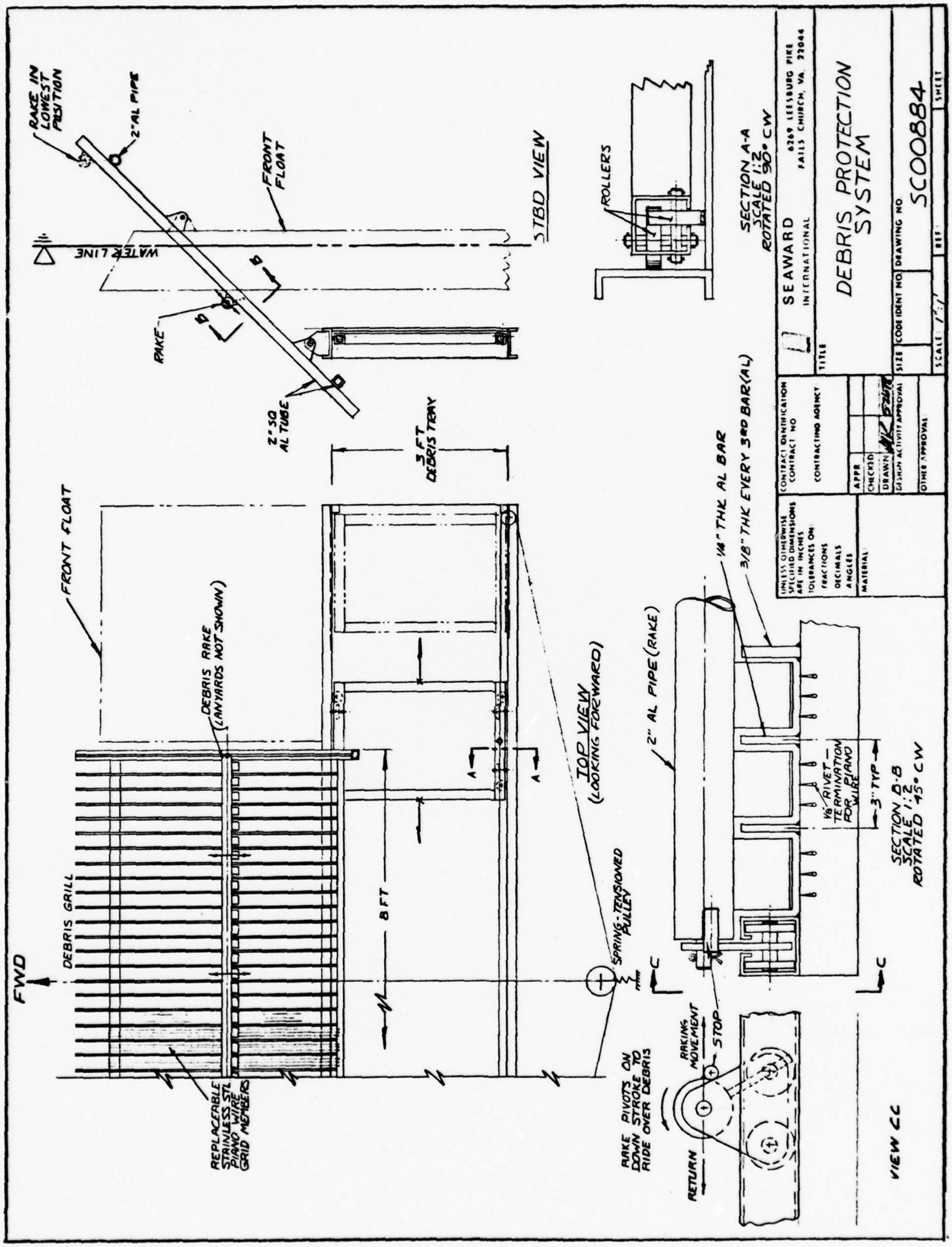


FIGURE A-12. DEBRIS PROTECTION SYSTEM

Roller-mounted on side channels of the debris grill, a pivoting debris rake moves debris up the inclined grill, dumping it onto the debris tray. The debris rake is manually operated by means of rope lanyards. The rake pivots so that while on the upstroke its "teeth" are meshed between the slats of the grill; it is free on the downstroke to pivot and ride over remaining small debris.

The debris tray is simply a smooth-bottomed tray with channel sides, provided for collection and dumping of debris. As mentioned earlier, the channel side-members of the collection tray also serve to stiffen the mounting of the front floats. A "sweeper cart" is mounted on rollers in its track between the side-channels of the collection tray. When manually operated, by means of rope lanyards and pulleys, the cart traverses its track from one side to the other, sweeping collected debris off the tray to either side of the front floats.

If absolutely necessary for handling of large debris, men could be stationed on either of the front floats. Equipped with pitchforks or longer staffs, they could guide larger floating debris out around the front floats, while operating at low skimming speeds. In this situation, the front floats should be equipped with a tethering rail, and the men be outfitted in tethered safety harnesses.

3.3 Hull

The proposed prototype hull design is basically very similar to that proposed in the December 1976 final report.[2] The basic catamaran hull construction is shown in Figure A-13. The hull specifications are listed in Table A-2.

The fore and aft sections of the deck have been shortened somewhat from the previous design, and the steps between the lower and upper decks are removable. This allows the lengthened lower deck to accommodate the skimming mechanism during storage for air

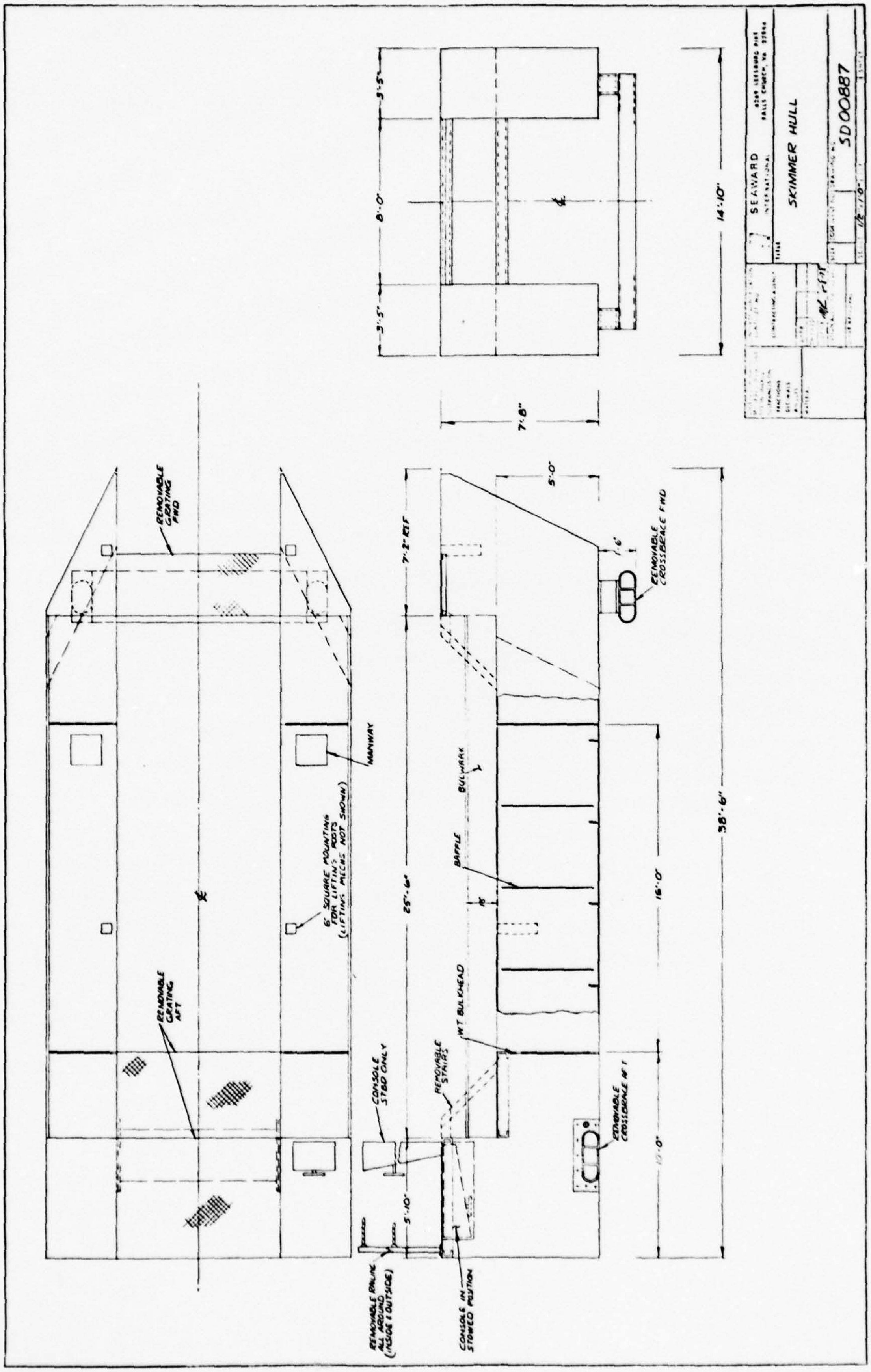


FIGURE A-13. SKIMMER HULL

TABLE 2. HULL SPECIFICATIONS

L.O.A.	38.5 ft
Beam	15.0 ft
Demihull Beam	3.5 ft
Operating Draft (including cross-member)	4.5 ft
Depth (including cross-member)	6.5 ft
Operating Displacement	44,800 lb
Weight	12,000 lb
Fuel Capacity	170 gal
Collected Oil Capacity	1,750 gal (.9 sp. gravity)
Ballast Capacity	4,500 lb
Maximum Speed (skimming section raised)	10 kt
Maximum Speed (skimming section lowered)	6 kt

Note: This table based on: 25,000 lb. weight of vessel and all auxiliary equipment, crew of six on board, maximum ballast of 10% of displacement.

transportability. The two demihulls of the catamaran structure are rigidly assembled with removable cross-members. The lower cross-members are streamlined for minimal drag and flow disruption. The lower, forward cross-member actually extends well below the bottom of the hull structures. This allows an extended freedom of vertical movement between the catamaran hull and the independently floated skimming center section. A pair of heavy, nylon shock-lines prevents the center section from bottoming out on the lower cross-member. The upper cross-members of the hull structure also serve as removable bridging decks between the hulls. The assembled structure provides a relatively stiff operating platform, with little relative motion between the demihulls.

An outer bulwark has been added to this design, affording some additional weather protection, without exceeding air transport storage limitations. The two demihulls are basically mirror images of each other, except for the control console, which is located on the aft deck of the starboard demihull. The aft section of each demihull contains a diesel-driven propulsion unit, hydraulic drive components, fuel tank, ballast pump, auxiliary equipment, and oil transfer pumps. The midships compartments provide for oil storage and ballasting. These are divided into four chambers separated by internal baffles, which thus function as preliminary oil-water separators. The forward compartments contain trim tanks for use in ballasting.

The proposed prototype hull is compatible with air transportability requirements and should meet all the design goals.

3.4 Propulsion

The propulsion system proposed for this prototype design is identical to that previously proposed in the December 1976 final report. Each demihull contains a Stewart and Stevenson Dieseldrive model DD-3-53-MN outdrive system. This system employs a lightened GM 3-53 two-cycle diesel engine coupled to a sidearm steering type

outdrive system. Further specifications of the outdrive systems are listed in the December 1976 final report.

Each engine is rated at 115 bhp, which is ample power to meet the minimum propulsive design requirement of 77 bhp; the reserve power is more than adequate for powering of the belt drive and auxiliary systems. The propulsion system controls are at the control console on the starboard demihull.

The diesel-drive system is completely standard with the exception of the vertical drive shaft length. This is a specially ordered lengthened unit, required to match the three-foot draft of the catamaran hull. The diesel outdrive system offers proven reliability, excellent manueverability, and compact size.

3.5 Oil Transfer Pumping System

To achieve the design goal of 300 gpm pumping capacity, two lobe-type pumps identical to those used in the OHMSETT test model would be used. The same 2000 psi hydraulic drive system and valving arrangement would also be used. One pump, hydraulic drive system, and valve assembly would be located in the engine compartment of each demihull. The systems will provide a nominal discharge pressure of 50 psi at the specified total capacity of 300 gpm. This is sufficient for transfer of 10,000-SSU oil through piping to the internal oil storage tanks, or through hoses to nearby external oil storage bags.

Oil pickup from the floating oil pick-up head is piped to the transfer pump through flexible, 4-inch I.D. suction hose. As described earlier, the pick-up head is designed to pickup oil from the surface of the collection area, with minimal water pickup. The transfer pumping rate should be adjusted appropriately, by means of a variable hydraulic flow control valve, to match the oil encounter rate. A pair of oil-water interface sensors, (float-type sensors) indicates to the operator the depth of oil in the collection area.

Oil discharged from the pumps would be directed either to external storage, or to the internal oil storage tanks within the demihulls. These tanks act as two stage oil-water separators and are piped to ensure that water overflow from the tanks is directed back into the skimmer for further separation of any entrained oil.

3.6 Hydraulic System

For flexibility of operation, safety, and reliability, the transfer pumping system, the belt drive, and optional auxiliary equipment are hydraulically powered. A schematic of the proposed hydraulic system is shown in Figure A-14. In the engine compartment of each demihull is contained a variable-flow, pressure compensated axial-piston hydraulic pump. The pump is directly driven by the diesel engine through a coupling attached to the raw water pump pulley (normally the fan belt pulley). Being pressure compensated, the pump supplies only enough flow to meet instantaneous powering requirements. The pump would be sized to provide full operating power at a minimum engine speed of 1000 rpm. A keel-cooler oil heat exchanger, hydraulic reservoir, and necessary piping would also be contained in each demihull. The hydraulic power supplies are sized to be fully redundant; either system could provide adequate power to meet normal operating requirements.

Hydraulic flow control valves, located at the control console, facilitate control of belt speed, and oil transfer pumping rate. Adjustable pressure relief valves would be adjusted to prevent damage to the systems should jamming occur in the belt drives or transfer pumps.

Pressure control valving and a small hydraulic accumulator permit the operator to control the squeeze roller pinch force. Another directional control valve permits retraction of the squeeze roller during belt maintenance operations.

Valving and quick-connect fittings would also be provided for use with optional auxiliary systems. Flexible hose and quick-connect fittings allow for rapid disassembly.

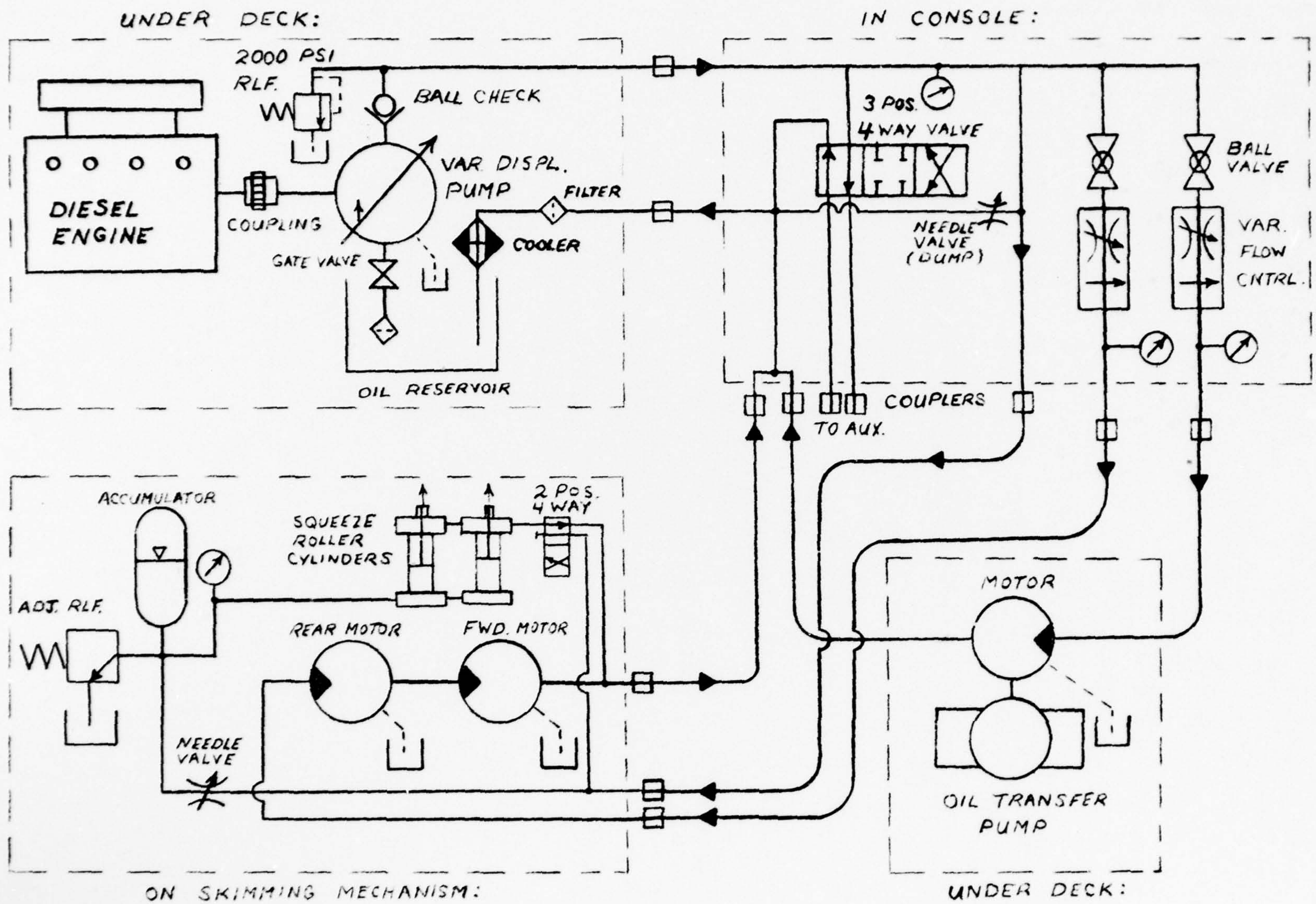


FIGURE A-14. SCHEMATIC OF HYDRAULIC SYSTEM

4.0 Auxiliary Systems

In order to enhance oil skimming performance and operational flexibility, and to meet design requirements for external oil storage and an air transport capability, certain auxiliary systems are required. This would include external oil storage and hoses, boom attachment fittings, mechanisms for lifting of the skimming mechanism, and air transport packaging.

4.1 External Oil Storage and Hoses

If recovering oil at the maximum rate of 300 gpm, the skimmer has only enough onboard oil storage capacity (1750 gallons) for six minutes of operation. For extended operation, some sort of external oil storage is a necessity. For offshore operations where tank trucks or barges would not be available, the skimmer would employ floating, towable, pillow-type storage tanks. They can be easily towed by the skimmer, are relatively lightweight, and can be folded into relatively small packages for storage. The available capacities and operational characteristics of commercially available, floating tanks are described in further detail in the December 1976 final report.

For handling of oil storage tanks, a small, 12 VDC, electrically powered winch and lifting davit would be provided and located on the aft deck of the port demihull.

4.2 Boom Attachment Fittings

For skimmer operation in connection with oil diverting booms, a pair of boom adaptor plates would be mounted on the front floats at the mouth of the device. These adaptor plates would be fitted with the standard Navy-style end connectors.

Where diverting booms are used, the angle and catenary of the boom should be limited such that the component of water velocity perpendicular to the boom does not exceed one knot at any point. It is recommended that the boom be smooth and streamlined

in shape to minimize flow disturbance and snagging on debris. The diverting boom used should have minimum draft (in order to minimize drag), should have good reserve buoyancy, good stability in currents, and adequate strength.

4.3 Skimmer Lifting-Post Mechanisms

In order to lift the skimming mechanism out of the water, and to provide access to the underside of the foam belt system, a set of four lifting-post mechanisms are provided with the prototype skimmer. The four "lifting posts" are removable, but are normally mounted vertically in mounting sockets built into the hulls. Two lifting posts are mounted on each hull, one on the fordeck, and one midships.

The basic construction of the skimmer lifting-post mechanism is shown in Figure A-15. At the top end of each lifting post, a small 12 VDC gearmotor winch provides lifting capacity of up to one ton. The four lifting mechanisms can be activated simultaneously or independently from the control console. For access to the belt system during maintenance operations, the skimming section could be lifted up to five feet above the level of the lower deck (assuming relatively mild sea conditions). A safety chain and snap hook on each post provide additional safety while working underneath the lifted skimming mechanism. A removable cross-walk deck would also be provided to allow men to stand over the center-well during maintenance operations. During storage or transport by tractor-trailer, the lifting posts would be removed and stowed in the engine compartments.

4.4 Air Transport Packaging

For air transport, the prototype skimmer can be disassembled and packaged on a special cargo platform for loading on a C-130 aircraft. The package will not fit, however, in the Coast Guard HC-130s that are equipped with optional electronic equipment located in the forward, overhead area.

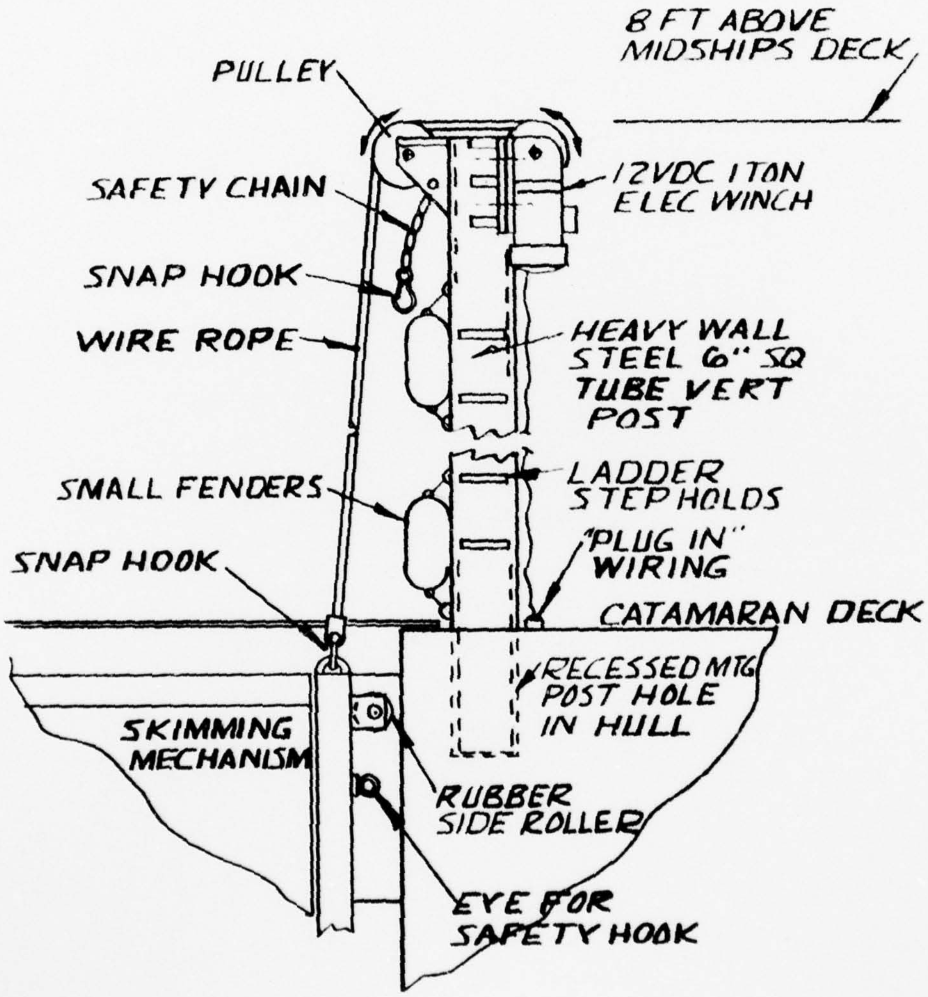


FIGURE A-15. SKIMMER LIFTING POST MECHANISM

The prototype system would be provided with a special loading pallet, such as Metric Systems A/E 29 H-1 modular aluminum cargo platform, equipped with all necessary cargo strapping and attachment points.

Figure A-16 shows the general outline of the prototype skimmer, as loaded into the C-130 aircraft. As shown, the hull cross-members have been removed and the demihulls strapped to the cargo platform approximately one foot apart. The front and rear floats have been removed from the skimming mechanism, and are stored between the demihulls. The skimming mechanism is strapped down on the midships deck. The debris tray is stored on top of the skimming mechanism. Hull cross-members and skimmer lifting posts are stored in front of the hulls. Miscellaneous equipment including the debris grill, guard railings, and removable decks are strapped down on the fore and aft decks. The central console is folded down into the starboard demihull. Other miscellaneous auxiliary gear is stored below decks in the aft compartment.

The total weight of the loaded package shall be no more than 25,000 pounds, the maximum cargo capacity of the C-130 aircraft. The prototype is designed for complete assembly in less than two hours, assuming availability of a crane and operator, with a trained and practiced assembly crew of four men.

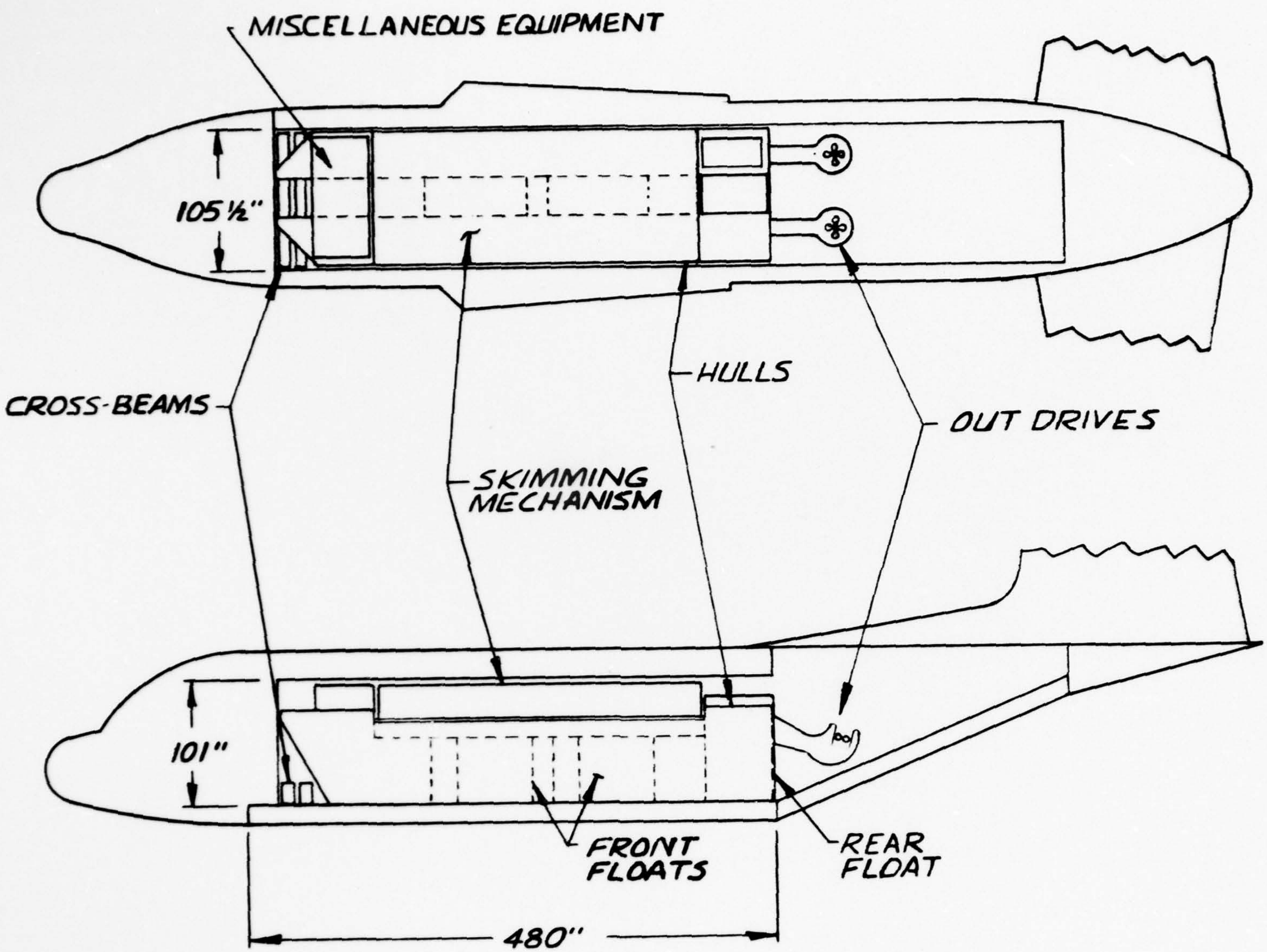


FIGURE A-16. SKIMMER LOADED ON C-130 AIRCRAFT

APPENDIX B

ADDITIONAL DETAILS ON OHMSETT TEST PLAN

OHMSETT Tests of Streaming Fiber

Modified Large-Scale Model, during 8-19 August 1977

A. GENERAL

These procedure are in addition to those discussed in the body of the report. They are presented here to provide guidance for further testing of this skimmer, or for similar large skimmers. These procedures are somewhat different than the normal OHMSETT test procedures.

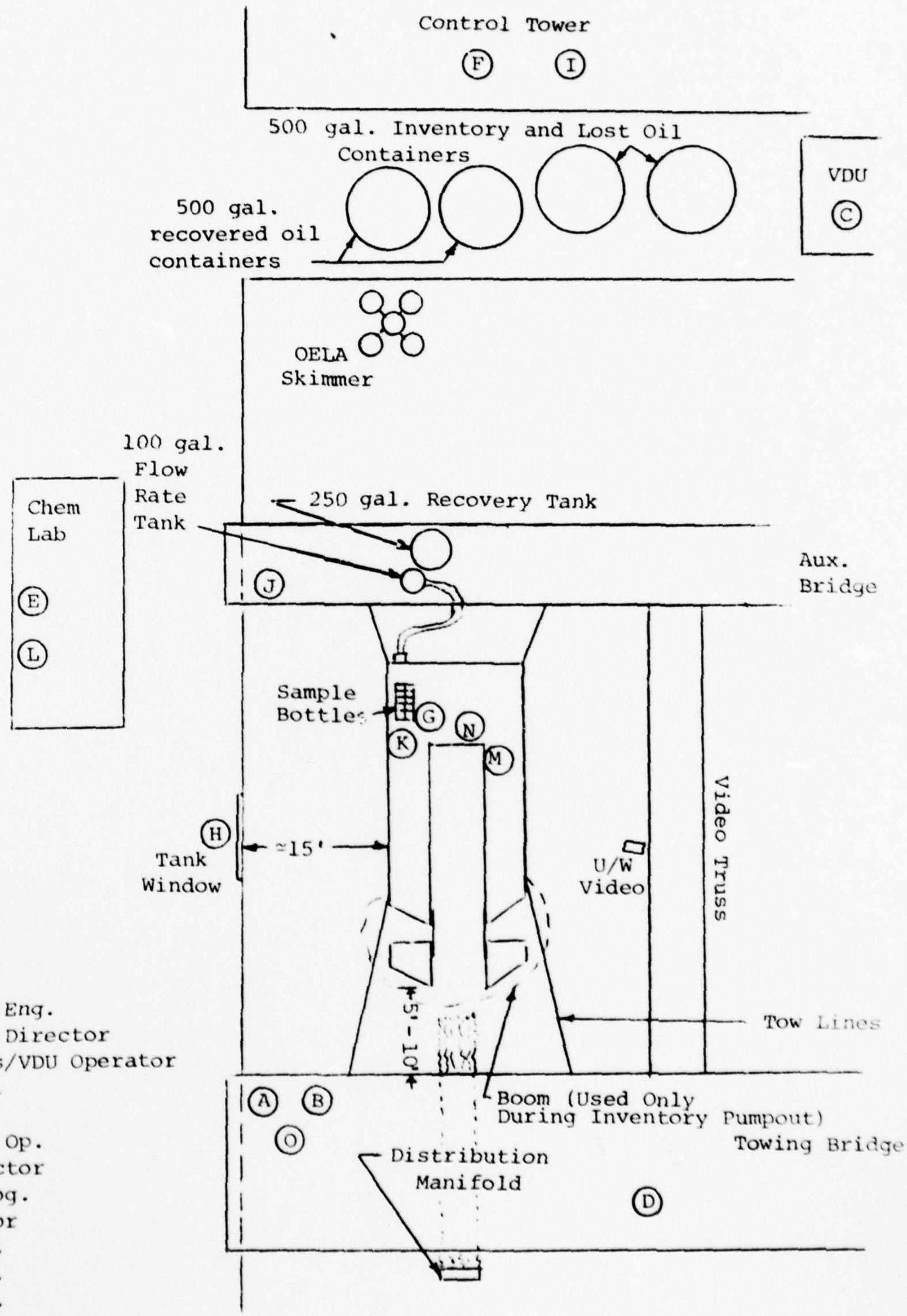
B. TEST LAYOUT

The required arrangement of the skimmer as installed for testing at OHMSETT is shown schematically in the following figure. Oil from the distribution manifold will be directed into the skimmer with the aid of fire hoses. Under no circumstances will the hoses be allowed to mix the oil into the water column or let it miss the mouth of the skimmer.

C. TEST PROCEDURES

1. Lower the fiber bundle into the water.
2. Pump water through the transfer pump and hose system to ensure that no residual oil remains in the lines.
3. Lower the dam at the front of the device, and remove the oil boom encircling the front of the skimmer.
4. Preset all skimmer controls for desired settings. Include the following:
    - 4.1 turnbuckle arm length (to adjust fiber sag)
    - 4.2 transfer pumping rate (from previous calibration)
    - 4.3 belt speed
    - 4.4 fiber depth
5. Make sure all recovery, flow-rate, lost oil, and inventory tanks to be used during the test are empty.

TEST LAYOUT



A OHMSETT Test Eng.
B OHMSETT Test Director
C Filter/Fluids/VDU Operator
D Oil Dist. Op.
E Chemist
F Control Room Op.
G Sample Collector
H OHMSETT Photog.
I Video Operator
J OHMSETT Tech.
K OHMSETT Tech.
L OHMSETT Tech.
M Seaward Eng.
N Seaward Tech.
O Coast Guard Proj. Off.

6. Set all external test parameters. Include:

   6.1 tow speed
   6.2 oil feed rate
   6.3 wave conditions

7. Pour in the inventory precharge (130 gallons unless otherwise specified).

8. Start the skimmer engine and belt.

9. Start the waves, waiting until proper buildup before commencing the pass.

10. Start towing (1/2 knot) and raise the dam.

11. Start the main tow (test speed) and oil feed.

12. As oil enters the device and joins with the oil inventory, start the transfer pump. The flow should be directed into the 250-gallon recovery tank, but not into the 100-gallon flow rate tank setting beside the recovery tank.

13. Start taking discrete samples from the pump discharge at 10 second intervals after starting the pump. (A special fitting, which includes a length of approximately 3/8-inch ID plastic tubing with a ball valve in the end, is to be connected into the transfer pump discharge line, for taking discrete flow rate samples from a point near the skimmer discharge connection.)

14. When oil starts pouring from the discharge hose, switch the hose from the 250-gallon recovery tank to the 100-gallon flow-rate tank, and start a stop watch. When oil encounter ceases (or if the 100-gallon tank becomes full) stop the stop watch and switch back to the 250-gallon tank. The quantity (oil and water) in the 100-gallon tank divided by the time is the Transfer Pumping Rate for that pass.

15. When the last of the oil slick enters the fiber area, stop the pump. The foot valves will prevent the oil from flowing back through the line. Discrete sample taking will cease.

16. When the skimmer stops moving, lower the dam in the front of the fiber bundle. The skimmer engine can be shut down. Insert foam leak preventers as required.

17. Stop the wave maker, if not already stopped.

18. Drop the skimmer boom from the towing bridge.

19. Tow back slowly, pushing the oil lost from the skimmer into the area at the beach end of the tow tank.

20. Skim the lost oil off the tank into a receiver using the OELA skimmer.

21. Repeat the procedure from Steps 8 through 20 for the next pass down the tank and all subsequent passes (up to five passes).

22. After the last tow-back, rig the short oil boom around the front of the skimmer. Pump out as much oil as possible from the fiber area, running the transfer pump until clear water comes out the end.

23. Raise the fiber bundle slowly out of the water, running the belt in reverse and squeezing, to drop as much oil as possible onto the water surface.

24. Pump all of the oil from the water surface (inside the skimmer) into the inventory tank using the small hand-held skimmer head and an air-diaphragm pump.

25. Connect a hose and pump up to the tanks on the auxiliary bridge (250 and 100-gallon tanks) and pump the contents to a 500-gallon recovery tank on the wash pad. Flush the hose with water from a fire hose to make sure all oil gets into the tank.

26. Record the oil volumes and analyze the contents of all recovered oil, lost oil, and inventory tanks using standard procedures.

27. Special procedure for new test oil: Before conducting tests with a new oil, the fibers and belt must be pre-oiled. To do this, lower the dam at the front of the skimmer and pour about 50-100 gallons of oil into the fiber area. Raise the fibers and belt through the oil, draining the oil in the same manner as after a normal run (run the belt and squeeze out the oil, etc.). Then, with the skimmer module elevated, flush out the oil between the hulls using a fire hose, and clean the oil off of the tank surface.

28. Special procedure for the last run of the day: To ensure that the same amount of equilibrium oil clings to the fibers as in previous tests, do the following on the last run of the day: tow the skimmer back to the starting point, place the boom around the bows, and raise the skimmer module to drain the oil onto the tank surface. However, do not pump out the oil to the inventory tank--just leave it between the hulls overnight. Grease the bearings, etc. The next morning lower the skimming module into the oil, thereby wetting the surfaces with oil, and then proceed with the inventory pumpout as though the run were just completed (Steps 22 through 26 of the Test Procedures).

D. PERSONNEL REQUIREMENTS

The identification letters correspond with the test layout sketch.

(A) OHMSETT TEST ENGINEER: Coordinates and executes through the OHMSETT TEST DIRECTOR requirements of the COAST GUARD PROJECT OFFICER as needed. Assists in data collection and decisions on subsequent test conditions. Responsible for completion of Test Data Sheets, and for informing the SEAWARD ENGINEER and COAST GUARD PROJECT OFFICER of the results as soon as possible after completing a test.

(B) OHMSETT TEST DIRECTOR: Controls all tank conditions, i.e. tow speed, oil distribution rate, waves. Single point of contact for requests by Coast Guard Project Officer.

(C) OHMSETT FILTER/VDU OPERATOR: Operates VDU reclamation unit as necessary. May act as technician when VDU operation is not necessary.

(D) OIL DISTRIBUTION OPERATOR: Technician to control and monitor the oil distribution operation. Also helps out as necessary in subsequent tank skimming operations.

(E) OHMSETT LAB CHEMIST: Key individual responsible for measuring oil content of samples; completes Oil Properties Data Sheet and provides the OHMSETT TEST ENGINEER with the results of all samples analyses as soon as available.

(F) OHMSETT CONTROL ROOM OPERATOR: Operates towing speed, and wave condition controls at settings directed by OHMSETT TEST DIRECTOR. Completes Ambient Conditions Data Sheet.

(G) SAMPLE COLLECTOR: Stationed on the skimmer to collect discrete recovery stream samples during the tests. Also assists in tank skimming operations after completion of the tests.

(H) OHMSETT PHOTOGRAPHER: Operates 35mm and 16 mm cameras.

(I) OHMSETT ELECTRONIC/VIDEO TECH: Maintains all video and recording equipment.

(J) OHMSETT TECHNICIAN: Controls the discharge hose from the skimmer; records the time to fill the flow rate tank; assists in taking recovered oil samples for laboratory analysis, skimming operations, and other tasks.

(K) OHMSETT TECHNICIAN: Assists the SEAWARD TECHNICIAN in operation of the skimmer; performs other tasks when available.

(L) OHMSETT TECHNICIAN: In Chemistry Lab assisting OHMSETT CHEMIST in measuring oil content in oil samples. Assists in sample gathering when necessary.

(M) SEAWARD ENGINEER: Consults with the COAST GUARD PROJECT OFFICER in all decisions affecting the test matrix; makes observations; adjusts skimmer parameters.

(N) SEAWARD TECHNICIAN: Aboard Skimmer to insure proper operation of skimmer during all tests.

(O) COAST GUARD PROJECT OFFICER: Makes all final decisions regarding test conditions and procedures after consulting with the OHMSETT TEST ENGINEER and the SEAWARD ENGINEER. Maintains Field Data Summary Sheet.

TEST DATA SHEET, PAGE 1

Run No.____________ Date____________ Time____________

Recorded by __________(initial)

Test Matrix No.________

INPUT DATA

Tow Speed ____________kts

Wave Length____________ft

Wave Height____________inches

Oil Type ____________

Oil Dist. Rate____________gpm

(Slick Thickness____________mm)

Fiber Depth ____________inches

Fiber/Belt Sag____________inches

Belt Speed ____________fps

Transfer Pump Rate Setting ____________gpm

OUTPUT DATA

Throughput Efficiency (T.E.)____________%

(T.E. Check ____________%)

Recovery Efficiency (R.E.)____________%

Oil Recovery Rate (C.R.R.)____________gpm

Transfer Pumping Rate____________gpm

Tow Force ____________lb

PHOTOGRAPHY

	Surface	U/W
Stills	______	______
Motion Pic.	______	______
Video	______	______

OIL DATA

Viscosity ________cs at ________ ^{o}F

Specific Gravity ____________

Oil/Water IFT ____________dyne/cm

Surface Tension____________dyne/cm

ENVIRONMENTAL DATA

Wind Speed ____________ mph

Wind Direction ____________

Air Temperature ____________ ^{o}F

COMMENTS:

TEST DATA SHEET, PAGE 2

OUTPUT DATA CALCULATIONS

THROUGHPUT EFFICIENCY	Total Volume, gal (1)		Average Fraction Oil (2)		Oil Volume, Gal	
Final Oil Inventory						
Inventory tank 1	____	x	____	=	____	
Inventory tank 2	____	x	____	=	____	
Subtotal						____(A)
Oil Recovered						
Recovery Tank 1	____	x	____	=	____	
Recovery Tank 2	____	x	____	=	____	
Subtotal						____(B)
Initial Oil Inventory						
Precharge Volume	____	x	____	=		____(C)

Oil Encountered					Fraction Encountered			
Pass 1	____	x	____	x	____	=	____	
Pass 2	____	x	____	x	____	=	____	
Pass 3	____	x	____	x	____	=	____	
Pass 4	____	x	____	x	____	=	____	
Pass 5	____	x	____	x	____	=	____	
Subtotal								____(D)

Throughput Efficiency (TE) = $\dfrac{\_\_\_\_(A) + \_\_\_\_(B) - \_\_\_\_(C)}{\_\_\_\_(D)}$ X 100% = ____(TE)

	Total Volume, gal (1)		Average Fraction Oil (2)		Oil Volume, Gal	
Losses on tow tank surface						
Loss tank 1	____	x	____	=	____	
Loss tank 2	____	x	____	=	____	
Subtotal						____(E)

Throughput Efficiency (Check) = $\dfrac{\_\_\_\_(D) - \_\_\_\_(E)}{\_\_\_\_(D)}$ = ____(TE Check)

RECOVERY EFFICIENCY

		Average Fraction Oil in Recovery Stream
Pass 1		____
Pass 2	+	____
Pass 3	+	____
Pass 4	+	____
Pass 5	+	____
	=	____(F)

Recovery Efficiency = $\dfrac{\_\_\_\_(F)}{\_\_\_\_(\text{No. of Passes})}$ x 100% = ____%(RE)

OIL RECOVERY RATE

	Total Volume, Gal	Sample Time, Sec	Transfer Pumping Rate, $\frac{gal}{sec}$ x 60 = gpm	Average Fraction Oil in Recovery Stream	Oil Recovery Rate, gpm
Rate Tank 1	____	____	____	____	____
Rate Tank 2	____	____	____	____	____
Rate Tank 3	____	____	____	____	____
Rate Tank 4	____	____	____	____	____
Rate Tank 5	____	____	____	____	____
Subtotals			____(H)		____(G)

Oil Recovery Rate, average = $\dfrac{\_\_\_\_(G)}{\_\_\_\_(\text{no. of passes})}$ = ____gpm (ORR)

Transfer Pumping Rate, average = $\dfrac{\_\_\_\_(H)}{\_\_\_\_(\text{no. of passes})}$ = ____gpm (TPR)

(1) Total volume of mixture upon which oil samples are based.

(2) Average of all samples taken.

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